N E U R O A R Q U I T E C T U R A

NUEVAS MÉTRICAS PARA EL DISEÑO ARQUITECTÓNICO A TRAVÉS DEL USO DE NEUROTECNOLOGÍAS.

NEUROARCHITECTURE: NEW METRICS FOR ARCHITECTURAL DESIGN THROUGH THE USE OF NEUROTECHNOLOGIES.

Autor / Author:

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PROGRAMA DE DOCTORADO EN ARQUITECTURA, EDIFICACIÓN, URBANÍSTICA Y PAISAJE

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Resumen

"Tomar posesión del espacio es el primer gesto humano". Así capturaba Le Corbusier lo fundamental de la relación humano-espacio. La dependencia del entorno lleva a adaptar el espacio a las necesidades. En este sentido, desde que la arquitectura apareciese hace más de 9000 años se han producido sucesivos actos de ordenación del espacio. El resultado es el espacio construido actual; nuestro mayor artefacto, dentro del que –hoy- determinadas sociedades emplean cerca del 90% de su tiempo. De forma que, al igual que el entorno natural, la arquitectura también tiene importantes efectos en el ser humano.

Estos efectos se han abordado a través de diferentes esfuerzos teóricos y prácticos, recibiendo más atención aquellas cuestiones más susceptibles de ser objetivadas. Así, existe un amplio bagaje sobre variados aspectos constructivos (como los materiales, las estructuras, o las instalaciones) que han cristalizado en estándares y normas técnicas. Sin embargo, no son los únicos efectos que tiene y debe resolver la arquitectura. El diseño de la arquitectura desencadena activaciones cerebrales, por lo que también son críticas las cuestiones relacionadas con los efectos sobre el procesamiento y valoración de la información (cognición), y las consecuentes reacciones adaptativas (emoción). El desarrollo cerebral, la recuperación de los pacientes, el estrés, el rendimiento en el trabajo y la creatividad, son algunos de los aspectos relacionados con esta dimensión cognitivo-emocional. Que haya sido sistemáticamente más difícil de estudiar, ha dado lugar a un menor recorrido al respecto.

La consciencia sobre esta necesidad, no obstante, no es algo nuevo. La idea de que la dimensión cognitivo-emocional también pueda y deba ser apoyada desde el diseño arquitectónico ha sido foco de reflexiones e investigaciones; no siempre han sido abordadas a través de la propia arquitectura, sino mediante las bases sentadas por otras aproximaciones. Entre ellas: la geometría, la fenomenología del espacio, la geografía de la experiencia, la filosofía, y la psicología; cada una con sus metodologías, de carácter cuantitativo o cualitativo. De alguna forma, estas aproximaciones "tradicionales" o "base" se han ido encadenando y combinando para resolver algunos de sus condicionantes específicos. Dilatadamente desarrolladas (a pesar de que cada una ha podido presentar una mayor notoriedad en determinados momentos), ofrecen un cuerpo muy experimentado para estudiar la dimensión cognitivo-emocional de la arquitectura.

Sin embargo, las aproximaciones tradicionales suelen contar con limitaciones derivadas –fundamentalmente- de dos asuntos: 1) los estímulos presentados; y 2) las evaluaciones empleadas. Por un lado, los estímulos habitualmente empleados son fotografías y vídeos; formatos que carecen de interactividad. Este empobrecimiento de la experiencia puede ser crítico, ya que en tanto que la simulación ambiental difiera de la realidad, los resultados también podrían estar distorsionados. Por otro lado, las evaluaciones usualmente se basan en el auto-reporte; sistemas de evaluación que son propensos al sesgo, ya que sólo registran aspectos conscientes de la respuesta humana. La importancia de esta limitación radica en que la mayoría de los procesos cognitivo-emocionales ocurren a nivel inconsciente. No obstante, las anteriores limitaciones no deslegitimizan el uso de las aproximaciones tradicionales. La dimensión cognitivo-emocional de la arquitectura requiere ser abarcada desde diferentes perspectivas. Así, la interrelación entre metodologías, especialmente entre las cuantitativas y las cualitativas, puede suponer un avance significativo.

De manera más reciente, han surgido nuevas herramientas para aproximarse a la dimensión cognitivo-emocional de la arquitectura. Estas, hasta cierto punto, superan las limitaciones descritas. Lo hacen a través de la incorporación de: 1) estímulos más similares a los espacios reales representados; y 2) evaluaciones más objetivas de la respuesta humana. Así, por un lado, en la actualidad existen formatos para la representación de entornos de manera realista. Por ejemplo, la realidad virtual y los panoramas 360º. Empleados junto a *displays* envolventes, permiten generar experiencias inmersivas e interactivas. Por otro lado, la neurociencia y sus tecnologías aplicadas permiten registrar e interpretar las reacciones neurológicas. Por ejemplo, el electroencefalograma, el electrocardiograma y la respuesta galvánica de la piel; los cuales permiten un registro de mayor objetividad. Sin embargo, aunque estas herramientas están siendo paulatinamente incorporadas a aproximaciones nuevas, sus potenciales no han sido suficientemente explorados en este ámbito de estudio.

El objetivo de la presente Tesis Doctoral es contribuir en la investigación y diseño de la dimensión cognitivo-emocional de la arquitectura, a nivel teórico y práctico. A nivel teórico implicó una revisión bibliográfica, contextualizada y crítica, sobre el estudio cognitivo-emocional de la arquitectura desde una perspectiva amplia, considerando el conjunto de aproximaciones: las tradicionales (o base) y las nuevas. Asimismo, también se abordaron ambas aproximaciones a nivel práctico. En cuanto a las tradicionales, la finalidad fue explorar los beneficios de combinar las metodologías cuantitativas y cualitativas más usualmente empleadas. En cuanto a las nuevas, la finalidad fue validar el uso de los actuales sistemas de simulación ambiental y examinar su uso combinado con los sistemas de registro neurofisiológico.

Abstract

"Taking possession of space is the first human action….". Thus did Le Corbusier capture the fundamentals of the human-space relationship. Dependence on the environment leads to the adaptation of space to needs. Since the advent of architecture more than 9000 years ago, successive space management activities have taken place. The result is the built environment, our greatest artifact, within which, today, some societies spend about 90% of their time. Like the natural environment, architecture has important effects on humans.

These effects have been addressed in different theoretical and practical approaches, with most attention being paid to issues more likely to be objectified. Thus, there exists extensive background on various aspects of construction (e.g., materials, structures, installations) that have crystallised into technical standards and regulations. However, these are not the only effects that architecture must address. Architectural design triggers brain activation, which raises critical questions about its effects on the processing and assessment of information (cognition) and consequent adaptive reactions (emotion). Brain development, patient recovery, stress, work performance and creativity are some of the aspects related to this cognitive-emotional dimension. The fact that the effects of cognition and emotion are systematically difficult to study means that there has been less research in this area.

The awareness of the need for more research, however, is not new. The idea that the cognitive-emotional dimension can and should be supported by architectural design has been the focus of earlier thinking and research. The issue has not always been approached from a solely architectural perspective; it has also been examined based on other disciplinary foundations. Among these are geometry, the phenomenology of space, geographical experience, philosophy and psychology. Each approach has its methodologies, quantitative or qualitative in nature. In various ways, these "traditional" or "base" approaches have been combined to address some of their specific determinants. These approaches (each has enjoyed greater popularity at different times) offer an extensively developed base from which to study the cognitive-emotional dimension of architecture.

However, traditional approaches often have limitations arising, fundamentally, from two issues: (1) the stimuli presented; and (2) the evaluations employed. On the one hand, the stimuli most commonly presented are photographs and videos, formats that lack interactivity. This experiential impoverishment can be critical, as the more that an environmental simulation differs from reality, the greater the chance that any results obtained will be distorted. On the other hand, evaluations are usually based on self-reports, which are prone to bias as they record only conscious human responses. This limitation is important because most cognitive-emotional processes take place unconsciously. However, these limitations do not delegitimise the traditional approaches. The cognitive-emotional dimension of architecture needs to be approached from different perspectives. Thus, the combination of methodologies, especially the quantitative and qualitative, can provide a significant step forward.

In recent times new tools have emerged to address the cognitive-emotional dimension of architecture. These, to some extent, overcome the above-mentioned limitations. They do so by incorporating: 1) stimuli more similar to the actual spaces represented; and 2) more objective assessments of human responses. On the one hand, formats now exist that can present environments realistically. Two examples are virtual reality and 360º panoramas. Used in conjunction with enveloping displays, these generate immersive, interactive experiences. On the other hand, neuroscience and its applied technologies allow researchers to record and interpret neurological reactions. For example, electrocardiogram, electrocardiogram and galvanic skin responses record human reactions with great objectivity. However, although these tools are gradually being incorporated into the new approaches, their potential has not been sufficiently explored in this field of study.

The objective of this doctoral thesis is to contribute to the research and design of the cognitive-emotional dimension of architecture, both on a theoretical and on a practical level. At the theoretical level this involves a bibliographic review, contextualised and critical, of the cognitive-emotional study of architecture from a broad perspective, considering various approaches, the traditional (or base) and new. Both approaches are addressed also on a practical level. The purpose in addressing the traditional approaches is to explore the benefits of combining the most commonly used quantitative and qualitative methodologies. The aim of addressing the new approaches is to validate the environmental simulation systems in current use and examine their operation in combination with neurophysiological measures.

Sommario

"Prendere possesso dello spazio è il primo gesto umano". Così sintetizzava Le Corbusier l'essenza del rapporto tra l'essere umano e lo spazio. La dipendenza dall'ambiente circostante lo ha portato ad un adattamento dello spazio in base alle esigenze. In questo senso, sin dalla prima apparizione dell'architettura oltre 9.000 anni fa, numerosi sono gli interventi per l'ordinamento dello spazio che si sono susseguiti. Il risultato è lo spazio costruito attuale, il nostro principale artefatto, all'interno del quale alcune società trascorrono al giorno d'oggi circa il 90% del loro tempo. Di conseguenza, l'importanza degli effetti che l'architettura produce sull'essere umano è pari a quella dell'ambiente naturale.

Tali effetti sono stati esaminati nel corso di numerosi studi tanto teorici quanto pratici, in particolar modo in relazione a questioni specifiche maggiormente oggettivabili. Questi studi hanno dato vita a un vasto bagaglio di conoscenze su svariati aspetti costruttivi (come i materiali, le strutture o le installazioni) che si sono cristallizzati in standard e norme tecniche. Tuttavia, ci sono anche altri effetti che l'architettura produce e che deve risolvere. La progettazione architettonica innesca anche delle attivazioni cerebrali; pertanto, altrettanto delicate sono le questioni correlate agli effetti sull'elaborazione e sulla valutazione delle informazioni (cognizione) e le conseguenti reazioni adattative (emozione). Lo sviluppo cerebrale, il processo di guarigione nei pazienti, lo stress, il rendimento sul posto di lavoro e la creatività sono solo alcuni degli aspetti correlati a questa dimensione cognitivo-emozionale. Essendo il loro studio sistematico più complicato, il loro approfondimento è rimasto più marginale,

pur essendo sempre esistita la consapevolezza della necessità di tale studio. L'idea secondo cui la progettazione architettonica possa e debba supportare anche la dimensione cognitivo-emozionale è stata sempre al centro di riflessioni e ricerche. Per affrontare questa dimensione non si è sempre partiti dall'architettura, ma piuttosto da principi e approcci di altre discipline, tra cui la geometria, la fenomenologia dello spazio, la geografia dell'esperienza, la filosofia e la psicologia, ognuna con le sue metodologie di carattere quantitativo e qualitativo. In questo modo, questi approcci "tradizionali" o "di base" si sono concatenati e accorpati per risolvere alcune delle loro condizionanti specifiche. Grazie al loro ampio sviluppo, indipendentemente dalla maggiore o minore notorietà che ognuno di questi approcci possa aver avuto in un determinato momento, disponiamo di un corpus strutturato e verificato per poter studiare la dimensione cognitivo-emozionale dell'architettura.

Tuttavia, gli approcci tradizionali presentano normalmente dei limiti derivanti principalmente da due questioni: 1) gli stimoli presentati; e 2) le valutazioni adoperate. Da un lato, gli stimoli generalmente utilizzati sono fotografie e video, entrambi formati privi di interattività. Tale impoverimento dell'esperienza può essere determinante, in quanto se la simulazione ambientale differisce dalla realtà, anche i risultati potrebbero apparire distorti. Dall'altro, gli studi si basano solitamente su autovalutazioni, sistemi di valutazione che registrano solo aspetti consci della risposta umana e che sono pertanto inclini a distorsioni dovute a bias. Tenendo in considerazione che la maggior parte dei processi cognitivo-emozionali avviene a livello inconscio, quest'ultimo costituisce un limite di grande rilievo. Ciononostante, i limiti summenzionati non delegittimano l'utilizzo degli approcci tradizionali. La dimensione cognitivo-emozionale dell'architettura deve essere affrontata da varie prospettive diverse. L'interrelazione tra varie metodologie, soprattutto tra quelle quantitative e quelle qualitative, può pertanto contribuire significativamente a un suo avanzamento.

In tempi più recenti sono stati creati nuovi strumenti per avvicinarsi alla dimensione cognitivo-emozionale dell'architettura. Tali strumenti riescono a superare, almeno in una certa misura, i limiti già descritti. Ci riescono tramite l'integrazione di: 1) stimoli più simili agli spazi reali rappresentati; e 2) valutazioni più oggettive della risposta umana. Da un lato, si sono creati formati per una rappresentazione realista degli ambienti circostanti. Ci riferiamo, ad esempio, alla realtà virtuale e alle panoramiche a 360º. L'utilizzo di tali tecnologie in combinazione con dei display curvi e avvolgenti consente di creare esperienze immersive e interattive. D'altro lato, la neuroscienza e le sue tecnologie applicate consentono di registrare e interpretare le reazioni neurologiche. Ad esempio, l'elettroencefalogramma, l'elettrocardiogramma e la risposta galvanica della pelle, che consentono una rilevazione maggiormente oggettiva. Ad ogni modo, nonostante l'integrazione progressiva di questi strumenti nei nuovi approcci, il loro potenziale non è stato ancora indagato a sufficienza in questo ambito di studio.

L'obiettivo della presente Tesi di Dottorato è contribuire alla ricerca e alla strutturazione della dimensione cognitivo-emozionale dell'architettura, a livello teorico e pratico. A livello teorico, ha richiesto una revisione bibliografica, contestualizzata e critica, sullo studio cognitivo-emozionale dell'architettura da una prospettiva più ampia, tenendo in considerazione tutti gli approcci nel loro insieme: quelli tradizionali (o di base) e quelli nuovi. Di pari passo, entrambi gli approcci sono stati esaminati anche a livello pratico. Per gli approcci tradizionali, il fine è stato approfondire i benefici derivanti dalla combinazione delle metodologie quantitative e qualitative più comunemente utilizzate. Per gli approcci nuovi, il fine è stato quello di verificare l'utilizzo degli attuali sistemi di simulazione ambientale ed esaminare il loro utilizzo in combinazione con i sistemi di registrazione neurofisiologica.

Resum

"Prendre possessió de l'espai és el primer gest humà". Així capturava Le Corbusier l'essència de la relació ésser humà-espai. La dependència de l'entorn porta a adaptar l'espai a les necessitats. En aquest sentit, des que l'arquitectura apareguera fa més de 9000 anys s'han produït successius actes d'ordenació de l'espai. El resultat és l'espai construït actual; el nostre major artefacte, dintre del qual –hui- determinades societats empren prop del 90% del seu temps. De manera que, igual que l'entorn natural, l'arquitectura també té importants efectes en l'ésser humà.

Aquests efectes s'han abordat a través de diferents esforços teòrics i pràctics, rebent més atenció aquelles qüestions més susceptibles de ser objectivades. Així, existeix un ampli bagatge sobre diversos aspectes constructius (com els materials, les estructures, o les instal·lacions) que han cristal·litzat en estàndards i normes tècniques. No obstant això, no són els únics efectes que té i deu resoldre l'arquitectura. El disseny de l'arquitectura desencadena activacions cerebrals, és per això que també són crítiques les qüestions relacionades amb els efectes sobre el processament i valoració de la informació (cognició), i les conseqüents reaccions adaptatives (emoció). El desenvolupament cerebral, la recuperació dels pacients, l'estrès, el rendiment en el treball i la creativitat, són alguns dels aspectes relacionats amb aquesta dimensió cognitiu-emocional. Que haja sigut sistemàticament més difícil d'estudiar, ha donat lloc a un menor recorregut sobre aquest tema.

La consciència sobre aquesta necessitat, no obstant, no és ninguna novetat. La idea que la dimensió cognitiu-emocional també puga i dega ser secundada des del disseny arquitectònic ha sigut focus de reflexions i investigacions; no sempre han sigut abordades a través de la pròpia arquitectura, sinó mitjançant les bases establertes per altres aproximacions. Entre elles: la geometria, la fenomenologia de l'espai, la geografia de l'experiència, la filosofia i la psicologia; cadascuna amb les seues metodologies, de caràcter quantitatiu o qualitatiu. D'alguna forma, aquestes aproximacions "tradicionals" o "base" s'han anat encadenant i combinant per a resoldre alguns dels seus condicionants específics. Dilatadament desenvolupades (tot i que cadascuna ha pogut presentar una major notorietat en determinats moments), ofereixen un cos molt experimentat per a estudiar la dimensió cognitiu-emocional de l'arquitectura.

No obstant això, les aproximacions tradicionals solen comptar amb limitacions derivades –fonamentalment- de dos assumptes: 1) els estímuls presentats; i 2) les avaluacions emprades. D'una banda, els estímuls habitualment emprats són fotografies i vídeos; formats que manquen d'interactivitat. Aquest empobriment de l'experiència pot ser crític, ja que si la simulació ambiental difereix de la realitat, els resultats també podrien estar distorsionats. D'altra banda, les avaluacions usualment es basen en l'auto-report; sistemes d'avaluació que són propensos al biaix, ja que només registren aspectes conscients de la resposta humana. La importància d'aquesta limitació radica en el fet que la majoria dels processos cognitiu-emocionals ocorren a nivell inconscient. No obstant això, les anteriors limitacions no deslegitimitzen l'ús de les aproximacions tradicionals. La dimensió cognitiu-emocional de l'arquitectura requereix ser abordada des de diferents perspectives. Així, la interrelació entre metodologies, especialment entre les quantitatives i les qualitatives, pot suposar un avanç significatiu.

D'una manera més recent, han sorgit noves eines per a aproximar-se a la dimensió cognitiu-emocional de l'arquitectura. Aquestes, fins a un cert punt, superen les limitacions descrites. Ho fan a través de la incorporació de: 1) estímuls més similars als espais reals representats; i 2) avaluacions més objectives de la resposta humana. Així, d'una banda, en l'actualitat existeixen formats per a la representació d'entorns de manera realista. Per exemple, la realitat virtual i els panorames 360º. Emprats junt a *displays* envoltants, permeten generar experiències immersives i interactives. D'altra banda, la neurociència i les seues tecnologies aplicades permeten registrar i interpretar les reaccions neurològiques. Per exemple, l' electrocardiograma, l'electrocardiograma i la resposta galvànica de la pell; els quals permeten un registre de major objectivitat. No obstant això, encara que aquestes eines estan sent gradualment incorporades a aproximacions noves, els seus potencials no han sigut prou explorats en aquest àmbit d'estudi

L'objectiu de la present Tesi Doctoral és contribuir en la investigació i disseny de la dimensió cognitiu-emocional de l'arquitectura, a nivell teòric i pràctic. A nivell teòric va implicar una revisió bibliogràfica, contextualitzada i crítica, sobre l'estudi cognitiu-emocional de l'arquitectura des d'una perspectiva àmplia, considerant el conjunt d'aproximacions: les tradicionals (o base) i les noves. Així mateix, també es van abordar ambdues aproximacions a nivell pràctic. Quant a les tradicionals, la finalitat va ser explorar els beneficis de combinar les metodologies quantitatives i qualitatives més usualment emprades. Quant a les noves, la finalitat va ser validar l'ús dels actuals sistemes de simulació ambiental i examinar el seu ús combinat amb els sistemes de registre neurofisiològic.

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Gracias.

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Estructura
de la Tesis Doctoral

El presente documento está estructurado en nueve capítulos. Cinco de ellos se destinan a recoger las versiones de autor de los artículos independientes que componen el cuerpo fundamental de la Tesis Doctoral. Todos ellos están publicados en revistas de impacto, referentes en sus áreas de conocimiento; lo que es muestra de la sólida transdisciplinariedad que exigió el desarrollo de la Tesis Doctoral. Los cuatro capítulos restantes, otorgan un marco común de carácter transversal. A continuación, se muestra la estructura del documento y se indica en cada artículo los índices de impacto de su revista en el año de publicación.

01 Introducción.

Presenta el contexto general en que se desarrolla la investigación.

02 Objetivos.

Presenta el objetivo, sub-objetivos, y motivaciones de la investigación.

03 Artículo 1.

Recoge el artículo de revista **"The cognitive-emotional design and study of architectural space: A scoping review of neuroarchitecture and its precursor approaches"**, publicado en "Sensors" (Q1 – 0.653 SJR 2019, Q1 - 3.275 JCR 2019)

04 Artículo 2.

Recoge el artículo de revista **"Psychological and physiological human responses to simulated and real environments: A comparison between photographs, 360 panoramas, and virtual reality"**, publicado en "Applied Ergonomics" (Q1 – 1.071 SJR 2017, Q1 - 2.435 JCR 2017).

05 Artículo 3.

Recoge el artículo de revista **"Digital space: Comparative evaluation of the latest architectural techniques"**, publicado en "EGA Revista de Expresión Gráfica Arquitectónica" (Q3 - 0.107 SJR 2017).

06 Artículo 4.

Recoge el artículo de revista **"User evaluation of neonatology ward design. An application of focus group and semantic differential"**, publicado en "HERD: Health Environments Research & Design Journal" (Q2 – 0.449 SJR 2017, Q3 - 1.387 JCR 2017).

07 Artículo 5.

Recoge el artículo de revista **"Multisensory stress reduction: A neuro-architecture study of paediatric waiting rooms"**, publicado en "Building Research & Information" (Q1 – 1.175 SJR 2019, Q1 - 3.887 JCR 2019).

08 Discusión.

Expone una interpretación de cuestiones complementarias y más globales a las recogidas en los artículos (capítulos 3 a 7), así como sus relaciones con los antecedentes científicos.

09 Conclusiones.

Resume las principales ideas, tras considerar y discutir los resultados, que dan respuesta a los objetivos de la investigación. Además, traza las líneas de investigación futuras.

Structure
of the Doctoral Thesis

This document is structured in nine chapters. Five of them are meant to collect the author's versions of the independent journal papers that make up the main body of the Doctoral Thesis. All of them have been published in journals of impact, which are referents in their areas of knowledge. This is a sign of the solid transdisciplinarity that the development of the Doctoral Thesis required. The remaining four chapters provide a common framework of a transversal nature. The structure of the document is shown below, with each paper indicating the impact indexes of its journal in the year of publication.

01
Introduction.

It presents the general context in which the research is taking place.

02
Objectives.

It presents the objective, sub-objectives, and motivations of the research.

03
Paper 1.

It contains the journal paper **"The cognitive-emotional design and study of architectural space: A scoping review of neuroarchitecture and its precursor approaches"**, published in "Sensors" (Q1 – 0.653 SJR 2019, Q1 - 3.275 JCR 2019).

04
Paper 2.

It contains the journal paper **"Psychological and physiological human responses to simulated and real environments: A comparison between photographs, 360 panoramas, and virtual reality"**, published in "Applied Ergonomics" (Q1 – 1.071 SJR 2017, Q1 - 2.435 JCR 2017).

05
Paper 3.

It contains the journal paper **"Digital space: Comparative evaluation of the latest architectural techniques"**, published in "EGA Revista de Expresión Gráfica Arquitectónica" (Q3 - 0.107 SJR 2017).

06
Paper 4.

It contains the journal paper **"User evaluation of neonatology ward design. An application of focus group and semantic differential"**, published in "HERD: Health Environments Research & Design Journal" (Q2 – 0.449 SJR 2017, Q3 - 1.387 JCR 2017).

07
Paper 5.

It contains the journal paper **"Multisensory stress reduction: A neuro-architecture study of paediatric waiting rooms"**, published in "Building Research & Information" (Q1 – 1.175 SJR 2019, Q1 - 3.887 JCR 2019).

08
Discussion.

It provides an interpretation of complementary and more global issues to those covered in the journal papers (chapters 3 to 7), as well as their relationship to the scientific background.

09
Conclusions.

It summarises the main ideas, after considering and discussing the results, which respond to the research objectives. It also outlines the lines of future research.

01 Introducción

Este capítulo presenta el contexto general que motiva la Tesis Doctoral y expone sus objetivos. Contiene dos apartados: 1) La repercusión cognitivo-emocional de la arquitectura; y 2) Aproximaciones a la dimensión cognitivo-emocional de la arquitectura. Estos apartados (a su vez divididos en sub-apartados) siguen una lógica progresiva, pero pueden ser consultados de manera independiente.

1. La repercusión cognitivo-emocional de la arquitectura

La arquitectura tiene múltiples efectos en las personas. Tal es la magnitud de esta influencia, que se ejecutan constante actos para adaptar el entorno, los cuales han dado lugar a nuestro mayor artefacto como especie: el espacio construido (Robinson, 2011, 2015). Como indica Zumthor (2014): "al principio no es ni mensaje ni signo, sino cobertura". Sin embargo, más allá de su carácter utilitario, la arquitectura tiene fuertes efectos cognitivo-emocionales (Hietanen & Korpela, 2004). Los efectos fisiológicos resultan ilustrativos, pudiendo derivar en consecuencias sobre el desarrollo humano y el estrés. En cuanto al desarrollo, una estimulación ambiental inadecuada afecta al desarrollo del cerebro (Perry, 2002). De hecho, un entorno que ofrezca una estimulación sensorial rica y equilibrada, contribuye al desarrollo de las funciones cognitivas (Bruer, 1997) y la creatividad (Malinin, 2014). En cuando al estrés, se ha demostrado que los elementos del entorno influyen (Averill, 1973; Glass & Singer, 1972). Este estrés asociado al ambiente puede dar lugar a peores recuperaciones en pacientes hospitalarios (Kiecolt-Glaser, Page, Marucha, MacCallum, & Glaser, 1998) e incluso una menor esperanza de vida (Glaser & Kiecolt-Glaser, 2005). Por consiguiente, los cambios en el entorno construido tienen importantes repercusiones (Gage, 2003). Algo de lo que los profesionales de la arquitectura son conscientes (Vannuci, Gori, & Kojima, 2014).

La intuición (o en un sentido más amplio y preciso: las *designerly ways of knowing* (Cross, 1982); formas de conocimiento distintas a las del conocimiento científico) ha sido, tradicionalmente, la principal forma de abordar la dimensión cognitivo-emocional de la arquitectura (Sternberg & Wilson, 2006). A través de estas formas de conocimiento, los arquitectos han explorado los fundamentos perceptivos de la experiencia arquitectónica, con el objeto de satisfacer las necesidades de este tipo en los usuarios. Ofrecen una gran economía de medios, lo que supone una ventaja para abordar los problemas que involucra el diseño arquitectónico (Powell, 1987): resultaría imposible evaluar la miríada de soluciones de diseño posibles; más aun teniendo en cuenta que las reglas para hacerlo pueden variar con el tiempo (por ejemplo, las necesidades de los individuos de sus casas cambian con el ciclo vital). Sin embargo, estas formas de conocimiento están especialmente ligadas a asuntos subjetivos en la toma de decisiones, por lo que característicamente quedan sometidas a sesgos y errores.

2. Aproximaciones a la dimensión cognitivo-emocional de la arquitectura

El conocimiento de estos efectos no es nuevo, de forma que la dimensión cognitivo-emocional de la arquitectura también ha sido investigada desde diferentes perspectivas. Podrían establecerse dos grandes grupos de aproximaciones: 1) aproximaciones tradicionales; y 2) aproximaciones nuevas. Esta clasificación hace referencia a que las primeras (tradicionales) han establecido los marcos teórico-prácticos a los que las segundas (nuevas) tratan de contribuir.

2.1. Aproximaciones tradicionales

El grupo de aproximaciones tradicionales incluye diversas aproximaciones. Entre otras, la geometría, la fenomenología del espacio, la geografía de la experiencia, la filosofía, y la psicología. Éstas se han ido encadenando para resolver algunos de sus condicionantes y limitaciones específicas, ofreciendo un cuerpo muy experimentado para estudiar la dimensión cognitivo-emocional de la arquitectura. Así, aunque no han sido adoptadas -amplia ni generalizadamente- como herramientas prácticas de diseño, constituyen parte del cuerpo teórico-práctico del que la arquitectura se ha servido para abordar la cuestión.

La psicología, que se ocupa de los procesos mentales involucrados en la experiencia (Gross, 2015), puede ser la aproximación tradicional más asentada científicamente. Esta fortaleza ante el paradigma positivista viene de los diversos instrumentos y metodologías, cuantitativos y cualitativos, con los que cuenta. Su rama centrada en el espacio, la "psicología ambiental", presenta la misma virtud (Bones & Secchiaroli, 1995; Kaminski, 1976). Las herramientas para enfrentar la dimensión cognitivo-emocional de la arquitectura son numerosas y diversas. Entre las cuantitativas, el *semantic differential* (diferencial semántico) es una de las más utilizados (Osgood, Suci, & Tannenbaum, 1957). Ésta se basa en la idea de que un concepto adquiere significado cuando un signo (palabra) puede provocar la respuesta que está asociada al objeto que representa; asumiendo complementariamente la existencia de una estructura delimitada subyacente en esta evaluación. Basándose en ésta, destacan los modelos de Mehrabian & Russel (*pleasure, arousal, dominance*; ver: Russell & Mehrabian, 1977) y de Külller (*affection, complexity, enclosedness, originality, pleasantness, potency, social status, unity*; ver Küller, 1972, 1980, 1991), que describen los estados emocionales relacionados con los efectos del ambiente en las personas. El diferencial semántico se ha utilizado en el contexto de la Ingeniería *Kansei*: un método de desarrollo de productos orientado al consumidor, que traduce estos conceptos en parámetros de diseño (Nagamachi, 1995). Se ha aplicado en diferentes sectores del mercado, incluyendo el arquitectónico (Kinoshita, Cooper, Hoshino, & Kamei, 2006; Sendai, 2011) y el urbano (Kinoshita et al., 2006; Llinares, Page, & Llinares, 2013). Entre las cualitativas, el *focus group* (grupo focal) es de utilidad para estudiar la relación entre un producto y su usuario (Morgan & Krueger, 1998) cuando, como en la mayoría de casos de diseño, hay una literatura limitada (Hsieh & Shannon, 2005). Ésta se basa en discusiones de grupo, cuidadosamente planificadas y dirigidas, orientadas a obtener información sobre un tema a través de las opiniones de los participantes. Puede ser de mayor ayuda que las entrevistas individuales para generar nuevas ideas y recordar aspectos relativos a experiencias pasadas (Kamberelis & Dimitriadis, 2005). Se ha aplicado en diferentes situaciones de diseño, como salas de operaciones (Watkins, Kobelja, Peavey, Thomas, & Lyon, 2011) y baños (Fink, Pak, & Battisto, 2010). Así, de manera individual estas herramientas han contribuido a obtener información útil sobre cómo satisfacer las necesidades cognitivas-emocionales de los usuarios. Sin embargo, las sinergias de combinarlas han sido poco investigadas en el caso concreto del diseño arquitectónico.

2.1.1. Limitaciones de las aproximaciones tradicionales

A pesar de su recorrido, las aproximaciones tradicionales suelen contar con dos limitaciones: 1) la validez de los estímulos presentados; y 2) la objetividad de las evaluaciones. La primera limitación (estímulos presentados), radica en que suelen utilizar estímulos no interactivos (como fotografías y vídeos). Estos estímulos empobrecen la experiencia (Ijsselsteijn, de Ridder, Freeman, & Avons, 2000), lo que ocasiona la problemática de que, dado que la simulación ambiental difiere substancialmente de la realidad, los resultados podrían estar distorsionados y no referirse al contexto físico (real) que se está estudiando. Así, aunque relativamente pueden llegar a aceptarse como válidas (Bateson & Hui, 1992), están limitadas. Además, la mayor parte de estos estímulos no permiten controlar las variables de diseño (como ocurre con los propios espacios físicos en los que se capturan). La segunda limitación (objetividad de las evaluaciones), radica en que se suelen utilizar auto-informes para cuantificar la experiencia del usuario. Dado que sólo registran los aspectos conscientes de las respuestas humanas, estas evaluaciones son propensas a sesgos (Schwarz & Strack, 1999), lo cual es de especial relevancia en el caso concreto de los aspectos cognitivo-emocionales, dado que la mayoría de éstos ocurren inconscientemente (Zaltman, 2003). Teniendo en cuenta estos puntos, los resultados deben contextualizarse.

2.2. Aproximaciones nuevas

El grupo de aproximaciones nuevas a la dimensión cognitivo-emocional de la arquitectura, intenta superar estas limitaciones. Para hacerlo, recurren a: 1) estímulos artificiales más similares a los estímulos físicos (a los espacios reales representados); y 2) evaluaciones más objetivas de las respuestas cognitivas-emocionales. En cuanto a los estímulos, se dispone de nuevos sistemas de simulación ambiental. Estos sistemas permiten simular los espacios físicos de una manera más realista, inmersiva e interactiva (Rheingold, 1991) en condiciones controladas de laboratorio. En cuanto a la evaluación, se dispone de la neurociencia y sus sistemas de registro o neuroimagen. Estas permiten registrar e interpretar las reacciones conductuales, fisiológicas y neurológicas (Winkielman, Berntson, & Cacioppo, 2001), proporcionando mayor objetividad (Poels & Dewitte, 2006; Reinerman-Jones, Cosenzo, & Nicholson, 2010; Reinerman-Jones, Sollins, Gallagher, & Janz, 2013) que, además, puede hacerse de manera continua y a tiempo real. Aunque estas tecnologías han estado disponibles durante décadas, su aplicación se está expandiendo actualmente, lo que está dando lugar a una explosión de disciplinas transdisciplinares con el prefijo "neuro", centradas en cuestiones cognitivo-emocionales de distintos contextos. La aplicación al marketing, a veces llamada "neuromarketing" (Lee, Broderick, & Chamberlain, 2007), es uno de los ejemplos más conocidos. Otro ejemplo es la "neuroestética", centrada en estudiar las bases neurológicas de la experiencia de la belleza (Chatterjee, 2013; Shimamura, 2013). Ambas, con predisposición a emplearse en los contextos propios de otras disciplinas. Que estas aproximaciones estén dando lugar a resultados satisfactorios es concluyente del avance que estas herramientas pueden suponer en la arquitectura.

2.2.1. Simulación ambiental

Las simulaciones ambientales son representaciones de entornos. Responden a la necesidad de representarlos (Rohrmann & Bishop, 2002), lo cual es especialmente importante cuando el espacio no puede ser inspeccionado, por su inaccesibilidad o porque aún no existe. Indistintamente del motivo de origen, el propósito general es representarlos lo más apropiadamente (de Kort, Ijsselsteijn, Kooijman, & Schuurmans, 2003), lo que dependerá de la finalidad de la simulación. De hecho, en algunas disciplinas como en la arquitectura, las simulaciones se convierten en parte fundamental de su lenguaje (Sainz, 2005). Al ser una necesidad vetusta, poseen una larga trayectoria (Sheppard & Salter, 2004). Así, existen distintos tipos que han ido incorporándose y reciclándose a medida que la tecnología lo ha posibilitado (Lange, 2001). La gama de sistemas de simulación ambiental viene dada por la combinación de un formato y un soporte.

2.2.1.1. Formatos

El formato de la simulación ambiental se refiere al estándar mediante el cual se codifica el entorno. Para clasificarlos, es posible englobarlos de acuerdo a su capacidad interactiva. Los dos tipos más usados en simulación ambiental para arquitectura son: la fotografía, y la realidad virtual (Beckmann, 1998). Por un lado, la fotografía capta imágenes del mundo físico a través de la acción de la luz (Sontag, 1977). Este tipo también incluye a los vídeos que, dado que son una secuencia de fotogramas (fotografías), genera la ilusión de movimiento. Simulaciones ambientales similares se pueden generar informáticamente:, como los renders, que son ampliamente utilizados cuando la totalidad o parte del ambiente arquitectónico a representar no existe (Iñarra, Juan, & Llinares, 2013). A pesar de la escasez de interactuación que presenta la fotografía y sus variantes, su realismo visual y facilidad de uso lo convierten en un grupo de formatos válidos y ampliamente usados

(Rosa, 1998). Además, la fotografía está recobrando popularidad con los recientes desarrollos alrededor de las fotografías esféricas panoramas 360º (Jacobs, 2004). Estas fotografías no se limitan a una única perspectiva tomada desde un punto concreto, sino que toman información sobre todo lo que envuelve ese punto, por lo que su visualización, que requiere de soportes adecuados, ofrece una mayor interactividad: el usuario decide, siempre desde el mismo punto, que perspectiva visualizar. Por otro lado, la realidad virtual genera informáticamente simulaciones que reemplazan la información sensorial propia del mundo físico para producir la sensación de "estar ahí" (Steuer, 1992). Esto no sólo implica la visión, sino que es posible generar simulaciones ambientales que estimulen otros canales sensoriales, lo que es especialmente interesante para enriquecer la experiencia. Por ejemplo, el olfato tiene importantes efectos cognitivos-emocionales en ciertas situaciones, como la reducción del estrés (Lehrner, Eckersberger, Walla, Pötsch, & Deecke, 2000), y el oído influye en cómo percibimos los entornos (Xu, Li, & Salvendy, 2007). En cuanto a su aplicación general en investigación, la realidad virtual permite modificar independientemente variables de un mismo espacio y registrar su efecto en el usuario. Todo con un bajo coste temporal y económico (Morganti, Carassa, & Geminiani, 2007), difícilmente alcanzable en el entorno físico. Esto convierte la realidad virtual en ideal para estudiar los efectos cognitivo-emocionales del entorno (McCall, Hildebrandt, Hartmann, Baczkowski, & Singer, 2016).

2.2.1.2. Soportes

El soporte de la simulación ambiental se refiere al dispositivo utilizado para mostrar el entorno. Para clasificarlos, es frecuente recurrir a la inmersión que ofrece: el grado en que el soporte aísla a su usuario del mundo físico (Rangaraju & Terk, 2001). De acuerdo a ésta, se establecen tres niveles: 1) soportes no-inmersivos, como los monitores de ordenador; 2) soportes semi-inmersivos, como las CAVE (*cave automatic virtual environment*; literalmente una cueva de pantallas que envuelven al usuario); y 3) soportes inmersivos; como los HMD (*head-mounted displays;* o de tipo casco). Esta inmersión puede resultar especialmente importante, dado que genera una mayor sensación de presencia: "la sensación de estar ahí" (Baños et al., 2004; Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015), lo que puede ser esencial para que la simulación ambiental genere estados emocionales similares a los que generarían los entornos representados (De Kort, Meijnders, Sponselee, & Ijsselsteijn, 2006). Probablemente, sea una de las razones por las cuales la mayor parte del interés actual recae en los soportes inmersivos (Sharples, Cobb, Moody, & Wilson, 2008). De hecho, los HMD han avanzado tanto que han pasado a ser dispositivos asequibles en usabilidad y economía (Parsons, 2015). Esta creciente popularización ha contribuido a que la realidad virtual se esté aplicando gradualmente a más campos.

2.2.1.3. La utilidad de los sistemas de simulación ambiental: validez y credibilidad

Los sistemas de simulación ambiental se encuentran bajo profundos cambios (de Kort et al., 2003). Nuevos formatos y soportes han aparecido (Rohrmann & Bishop, 2002), y su uso por parte de los profesionales e investigadores ha aumentado (Bishop & Rohrmann, 2003). Efervescencia por la cual, a pesar de que se han desarrollado muchos estudios sobre la simulación de entornos, las investigaciones anteriores podrían ser ahora insuficientes (Lange, 2011). De esta forma, resulta esencial actualizarlas para incorporar los avances. Objetivo que pasa por estudiar su utilidad.

La actualización de este conocimiento sobre la utilidad de los sistemas de simulación ambiental es conceptualmente diferente de acuerdo a la función para la cual se utilicen. Esencialmente, pueden desempeñar dos grandes funciones: como vehículo para 1) investigar la percepción humana; o para 2) expresar aspectos de diseño. La primera función ha encontrado afinidad en la psicología ambiental (Sheppard & Salter, 2004). La segunda función, en el diseño en general (Clipson, 1993). Así, el estudio de la utilidad de los sistemas de simulación ambiental debe abordarse según el ámbito.

Para estudiar la utilidad de las simulaciones en psicología ambiental, suele recurrirse al concepto de "validez". Este concepto se refiere a la capacidad de evocar en el usuario una respuesta similar a la del entorno físico representado (Rohrmann & Bishop, 2002). Es decir, que el entorno simulado genere un efecto cognitivo-emocional similar al entorno real. Esto se basa en la lógica del "realismo comportamental", según la cual una simulación ambiental es mejor cuanto más similares sean las respuestas evocadas por los entornos físicos y representados (Freeman, Avons, Meddis, Pearson, & Ijsselsteijn, 2000). En general, los resultados de los estudios publicados muestran que las simulaciones ambientales tienden a funcionar en este sentido (Villa & Labayrade, 2012). Sin embargo, además de la desactualización propia de la aparición de nuevos sistemas de simulación ambiental, los estudios presentan dos limitaciones en cuanto al estudio de la respuesta cognitivo-emocional: no se profundiza en la respuesta psicológica (la mayoría sólo comparan la respuesta de preferencia); y no se explora la respuesta neurofisiológica.

Para estudiar la utilidad de las simulaciones en diseño, suele recurrirse al concepto de "credibilidad". Este concepto se refiere a la calidad percibida de la representación (Buller & Burgoon, 1996). Es una cuestión compleja, por lo cual amalgama múltiples aspectos. Distintos trabajos se han orientado a identificarlos exhaustivamente (Appleyard, 1977; Sheppard, 1689). Estos aspectos han llegado a sintetizarse por diversos autores (Pietsch, 2000; Radford et al., 1997) en tres: 1) precisión, la exactitud que permite al observador adquirir conocimiento similar al de la observación ilimitada del diseño; 2) realismo, la generación de una experiencia cercana a la real; y 3) abstracción, relacionada con el detalle que contiene la representación. Por separado, estos aspectos han sido extensamente experimentados en diferentes casos (por ejemplo, para estudiar la comunicación visual de proyectos paisajísticos: Downes & Lange, 2015), y los tres en conjunto han sido ampliamente utilizados para estudiar los sistemas de simulación ambiental habituales. Sin embargo, aunque la información técnica sobre los nuevos formatos y soportes de representación ambiental es amplia (Orland, 1993), no encontramos estudios comparativos sobre el efecto independiente de los nuevos formatos o soportes en cuanto a su credibilidad.

2.2.2. Neurociencia

La neurociencia estudia el sistema nervioso (Garland, 2004). Sobre la base de que está prestablecido para todos los seres humanos, ha proporcionado conocimiento sobre su funcionamiento (Grabenhorst & Rolls, 2011; Kircher & David, 2003). En origen la neurociencia contaba con pocas vías. Se limitaba al examen de pacientes con lesiones neuronales (Cela-Conde, Agnati, Huston, Mora, & Nadal, 2011), lo que a veces se ha considerado como anécdotas informativas (Chatterjee, 2011). Sin embargo, con el desarrollo de las herramientas de neuroimagen, que registran las respuestas cerebrales de manera no invasiva (Dirican & Göktürk, 2011; Ray & Oathes, 2003), se ha podido observar el funcionamiento del sistema nervioso de individuos sanos. Hoy en día son indispensables para explorar los procesos cognitivo-emocionales humanos (Cela-Conde et al., 2013).

Las herramientas para obtener estos registros son varias, y cubren distintas porciones y manifestaciones del sistema nervioso. Algunas de las más usualmente empleadas en las aplicaciones de la neurociencia a otras disciplinas, por su relativa facilidad instrumental, son: el electroencefalograma (EEG), la variabilidad del ritmo cardíaco (HRV), y la respuesta electrodérmica (EDA; también llamada "respuesta galvánica de la piel", o GSR). El EEG registra variaciones de voltaje derivadas del flujo iónico entre las neuronas del cerebro. Esto implica que los registros corresponden mayormente a las zonas más superficiales: las corticales (Niedermeyer & da Silva, 2005). Para analizarlo, generalmente se recurre a clasificar la señal dentro de frecuencias definidas (Sanei & Chambers, 2013) -lo que se basa en la idea que el cerebro está conformado por distintas redes, cada una operando a su frecuencia- y a establecer relaciones entre estas frecuencias (Darvas, Miller, Rao, & Ojemann, 2009). Su resolución temporal puede llegar 1 milisegundo y la espacial a 10 milímetros. Esta excelente resolución temporal permite analizar las fluctuaciones estereotipadas generadas por determinados estímulos (Picton et al., 2000). Entre otras aplicaciones, el EEG se ha utilizado para estudiar la carga mental (Lotte et al., 2018). Por otra parte, el HRV registra variaciones de tiempo entre latidos del corazón (Goldman, 1976). Para analizarlo, generalmente se recurre a estudios en el dominio del tiempo o en el dominio de la frecuencia (Berntson et al., 1997). Su medición se ha utilizado, por ejemplo, para estudiar el estrés (Kim et al. 2018). Otra herramienta es la EDA, que registra variaciones en las propiedades eléctricas de la piel, como consecuencia del sudor (Boucsein, 2012). Aunque el sudor juega un papel importante en otros procesos corporales, también se relaciona con la actividad simpática (Dawson, Schell, & Filion, 2007), por lo que resulta apropiada para estudiar la activación emocional (Benedek & Kaernbach, 2010). Por esto, entre otras funciones la EDA se ha utilizado para estudiar la atención (Prokasy, 2012). Además, existen otras herramientas. Entre ellas, la resonancia magnética funcional (fMRI), la magnetoencefalografía (MEG), la electromiografía (MEG), la pupilometría, y el *eye-tracking* (o seguimiento ocular). Dada la complejidad del sistema nervioso, todas estas herramientas son insuficientes para explicar su funcionamiento plenamente. No obstante, ofrecen información valiosa sobre sus procesos subyacentes.

2.2.3. Simulación ambiental y neurociencia, combinadas

La simulación ambiental y la realidad virtual pueden combinarse (Hemeida & Mostafa, 2017; Riva, 2003). Esto permite presentar ambientes mientras se toman los registros neurofisiológicos del usuario (Bohil, Alicea, & Biocca, 2011; Cho & Kim, 2017; Ergan, Radwan, Zou, Tseng, & Han, 2019; Merril, 1997; Radwan & Ergan, 2017). Sinergia que resulta atractiva tanto para la investigación clínica (Tarr & Warren, 2002), como para la arquitectura (Jelić, Tieri, De Matteis, Babiloni, & Vecchiato, 2016). En este sentido, cada vez se está utilizando en más estudios para investigar las bases psicológicas (Pasqualini, Llobera, & Blanke, 2012) y neuronales de distintos aspectos involucrados en cómo el ser humano se relaciona con el espacio que le rodea (Sanchez-Vives & Slater, 2005). Este tándem de herramientas permite evaluar la dimensión cognitivo-emocional de la arquitectura desde una nueva perspectiva (Chiamulera et al., 2017). Sin embargo, aún hay pocos trabajos prácticos centrados en la mejora del diseño arquitectónico a través del empleo de la neurociencia y sus tecnologías de registro o neuroimagen.

2.2.4. Neuroarquitectura

La neurociencia se está incorporando al estudio de la experiencia arquitectónica (Linaraki & Voradaki, 2012). Al igual que con las aproximaciones tradicionales, su incorporación al diseño y estudio de la arquitectura, incentivada por la necesidad de generar conocimiento científico, ha sido gradual. Una de las primeras formulaciones más explícitas sobre la incorporación de conocimientos de la neurociencia a la arquitectura fue la de Neutra (1954). Expuso que la arquitectura debía orientarse a satisfacer las necesidades neurológicas de sus usuarios, incorporando la investigación disponible en el desarrollo de los diseños arquitectónicos: "Si realmente queremos ajustar la arquitectura del medio construido a la vida, y asentarla de este modo sobre una base fisiológica, debemos dar el paso decisivo y trasponer las abstracciones de la geometría euclidiana". Enfoque que, aunque se basaba en principios entonces no completamente demostrados y no tan fácilmente extrapolables al ejercicio de la arquitectura, resultaba difícil de desacreditar. El punto en que este conocimiento empieza a ser accesible a los arquitectos, tardaría años en llegar. Según determinados autores (Robinson & Pallasmaa, 2015), el hito podría quedar marcado por la publicación de "The Embodied Mind" (Varela, Thompson, & Rosch, 2016). Obra en la que sus autores acuñan el término de "neurofenomenología", tratando de conciliar la mirada científica con la experiencia (Vijayan & Embi, 2019). Indistintamente, hoy existen menos vacilaciones sobre si la neurociencia puede ayudarnos a entender cómo percibimos y nos influye emocionalmente el espacio (Sternberg & Wilson, 2006).

La disciplina derivada suele recibir el nombre de "neuroarquitectura" (Chiamulera et al., 2017). Dos líneas destacan en la exploración de las bases neurocientíficas de la arquitectura: el proceso de diseño, y la experiencia de la arquitectura (Arbib, 2015). La primera línea (proceso de diseño), ha sido ampliamente desarrollada en el arte en general, y cuenta con progresos en el ámbito arquitectónico. Por ejemplo, planteamientos sobre cómo incorporar este conocimiento al proceso de diseño (Banasiak, 2012; Edelstein & Sax, 2014; Manganelli et al., 2012). La segunda línea (experiencia de la arquitectura), amalgama aspectos de diseño. Los más frecuentemente estudiados: la orientación, cuyas investigaciones tienen relevancia directa a la hora de mejorar las estrategias de navegación (Napieralski et al., 2014); la luz, abordada tanto desde fines estéticos como centrados en la salud (Edelstein, Doctors, et al., 2008; Ellis, Gonzalez, & McEachron, 2013); y la acústica, habiéndose encontrado relación entre el ruido y variadas consecuencias cognitivas-emocionales en el ser humano (Ising & Raun, 2000). Los resultados apoyan la utilidad de esta aproximación nueva a la dimensión cognitivo-emocional de la arquitectura (Chow, 2015; Kayan, 2011). Sin embargo, aunque la investigación neurocientífica es extensa y rigurosa, la neuroarquitectura es emergente (Dance, 2017). Los esfuerzos están dispersos y no se ha establecido un marco común. La novedosa y compleja naturaleza de la neuroarquitectura, hace que sea importante revisar sus avances.

01 Introduction

This chapter presents the general context that motivates the Doctoral Thesis and sets out its objectives. It contains two sections: 1) The cognitive-emotional impact of architecture; and 2) Approaches to the cognitive-emotional dimension of architecture. These sections (themselves divided into sub-sections) follow a progressive logic, but can be consulted independently.

1. The cognitive-emotional impact of architecture

Architecture has multiple effects on people. Such is the magnitude of this influence, that constant acts are performed to adapt the environment, which have given our greatest artefact as a species: the built space (Robinson, 2011, 2015). As Zumthor (2014) points out: "at first it is neither message nor sign, but cover". However, beyond its utilitarian character, architecture has strong cognitive-emotional effects (Hietanen & Korpela, 2004). The physiological effects are illustrative and can have consequences on human development and stress. In terms of development, inadequate environmental stimulation affects brain development (Perry, 2002). Indeed, an environment that offers rich and balanced sensory stimulation contributes to the development of cognitive functions (Bruer, 1997) and creativity (Malinin, 2014). In terms of stress, environmental elements have been shown to be influential (Averill, 1973; Glass & Singer, 1972). This stress associated with the environment can lead to poorer recoveries in hospital patients (Kiecolt-Glaser, Page, Marucha, MacCallum, & Glaser, 1998) and even shorter life expectancy (Glaser & Kiecolt-Glaser, 2005). Consequently, changes in the built environment have important implications (Gage, 2003). Architecture professionals are aware of this (Vannuci, Gori, & Kojima, 2014).

Intuition (or in a broader and more precise sense: the designerly ways of knowing (Cross, 1982); forms of knowledge other different of scientific knowledge) has traditionally been the main way of approaching the cognitive-emotional dimension of architecture (Sternberg & Wilson, 2006). Through these forms of knowledge, architects have explored the perceptual foundations of architectural experience in order to meet the perceptual needs of users. They offer a great economy of means, which is an advantage in addressing the problems involved in architectural design (Powell, 1987): it would be impossible to evaluate the myriad of possible design solutions, especially as the rules for doing so may change over time (for example, individuals' needs for their homes change over the life cycle). However, these forms of knowledge are especially linked to subjective decision-making issues, and are therefore characteristically subject to bias and error.

2. Approaches to the cognitive-emotional dimension of architecture

Knowledge of these effects is not new, so that the cognitive-emotional dimension of architecture has also been investigated from different perspectives. Two main groups of approaches could be established: 1) base approaches; and 2) new approaches. This classification refers to the fact that the former (base) approaches have established the theoretical-practical frameworks to which the latter (new) approaches try to contribute.

2.1. Base approaches

The group of base approaches includes several approaches. Among others, geometry, the phenomenology of space, geographical experience, philosophy and psychology. These have been linked together to resolve some of their specific constraints and limitations, offering a very experienced body for studying the cognitive-emotional dimension of architecture. Thus, although they have not been widely or generally adopted as practical design tools, they constitute part of the theoretical-practical body of knowledge that architecture has used to address the issue.

Psychology, which deals with the mental processes involved in experience (Gross, 2015), may be the most scientifically established base approach. This strength in the face of the positivist paradigm comes from the various quantitative and qualitative tools and methodologies at its disposition. Its branch focused on space, "environmental psychology", has the same virtue (Bones & Secchiaroli, 1995; Kaminski, 1976). The tools for dealing with the cognitive-emotional dimension of architecture are numerous and diverse. Among the quantitative ones, the semantic differential is one of the most widely used (Osgood, Suci, & Tannenbaum, 1957). This is based on the idea that a concept acquires meaning when a sign (word) can elicit the response that is associated with the object it represents; it further assumes the existence of a bounded structure underlying this evaluation. Based on this, the models of Mehrabian & Russell (pleasure, arousal, dominance; see: Russell & Mehrabian, 1977) and Külller (affection, complexity, enclosedness, originality, pleasantness, potency, social status, unity; see Küller, 1972, 1980, 1991), which describe emotional states related to the effects of the environment on people, stand out. The semantic differential has been used in the context of Kansei Engineering: a consumer-oriented product development method, which translates these concepts into design parameters (Mitsuo Nagamachi, 1995). It has been applied in different market sectors, including architectural (Kinoshita, Cooper, Hoshino, & Kamei, 2006; Sendai, 2011) and urban (Kinoshita et al., 2006; Llinares, Page, & Llinares, 2013). Among the qualitative ones, the focus group is useful to study the relationship between a product and its user (Morgan & Krueger, 1998) when, as in most design cases, there is limited literature (Hsieh & Shannon, 2005). It is based on carefully planned and conducted group discussions aimed at eliciting information about a topic through the opinions of the participants. It can be more helpful than individual interviews in generating new ideas and recalling aspects of past experience (Kamberelis & Dimitriadis, 2005). It has been applied in different design situations, such as operating rooms (Watkins, Kobelja, Peavey, Thomas, & Lyon, 2011) and bathrooms (Fink, Pak, & Battisto, 2010). Thus, individually these tools have contributed useful information on how to meet the cognitive-emotional needs of users. However, the synergies of combining them have been little investigated in the specific case of architectural design.

2.1.1. Limitations of the base approaches

Despite their success, the base approaches tend to have two limitations: 1) the validity of the stimuli presented; and 2) the objectivity of the assessments. The first limitation (presented stimuli) is that they tend to use non-interactive stimuli (such as photographs and videos). These stimuli impoverish the experience (Ijsselsteijn, de Ridder, Freeman, & Avons, 2000), which causes the problem that, since the environmental simulation differs substantially from reality, the results may be distorted and not refer to the (real) physical context being studied. Thus, although they can be relatively accepted as valid (Bateson & Hui, 1992), they are limited. Moreover, most of these stimuli do not allow for control of design variables (such as the physical spaces in which they are captured). The second limitation (objectivity of evaluations) is that self-reports are often used to quantify user experience. Since they only record the conscious aspects of human responses, these assessments are prone to bias (Schwarz & Strack, 1999), which is of particular relevance in the specific case of cognitive-emotional aspects, since most of these occur unconsciously (Zaltman, 2003). Bearing these points in mind, the results should be contextualised.

2.2. New approaches

The group of new approaches to the cognitive-emotional dimension of architecture tries to overcome these limitations. To do so, they use: 1) artificial stimuli more similar to physical stimuli (to the actual spaces represented); and 2) more objective assessments of cognitive-emotional responses. In terms of stimuli, new environmental simulation systems are available. These systems allow physical spaces to be simulated in a more realistic, immersive and interactive way (Rheingold, 1991) under controlled laboratory conditions. In terms of assessment, neuroscience and its recording or neuroimaging systems are available. These allow recording and interpretation of behavioural, physiological and neurological reactions (Winkielman, Berntson, & Cacioppo, 2001), providing greater objectivity (Poels & Dewitte, 2006; Reinerman-Jones, Cosenzo, & Nicholson, 2010; Reinerman-Jones, Sollins, Gallagher, & Janz, 2013) which, in addition, can be done continuously and in real time. Although these technologies have been available for decades, their application is now expanding, leading to an explosion of transdisciplinary disciplines with the prefix “neuro”, focusing on cognitive-emotional issues in different contexts. The application to marketing, sometimes called “neuromarketing” (Lee, Broderick, & Chamberlain, 2007), is one of the best known examples. Another example is “neuroaesthetics”, which focuses on studying the neurological basis of the experience of beauty (Chatterjee, 2013; Shimamura, 2013). Both are predisposed to be used in the contexts of other disciplines. The fact that these approaches are producing satisfactory results is conclusive of the progress that these tools can make in architecture.

2.2.1. Environmental simulation

Environmental simulations are representations of environments. They respond to the need to represent them (Rohrmann & Bishop, 2002), which is especially important when the space cannot be inspected, because of its inaccessibility or because it does not yet exist. Regardless of the reason, the general aim is to represent spaces as appropriately as possible (de Kort, Ijsselsteijn, Kooijman, & Schuurmans, 2003), which will depend on the purpose of the simulation. Indeed, in some disciplines such as architecture, simulations become a fundamental part of their language (Sainz, 2005). As a long-standing necessity, they have a long history (Sheppard & Salter, 2004). Thus, there are different types that have been incorporated and recycled as technology has made it possible (Lange, 2001). The range of environmental simulation systems is determined by the combination of a format and a display.

2.2.1.1. Formats

The format of the environmental simulation refers to the standard by which the environment is encoded. In order to classify them, it is possible to group them according to their interactive capacity. The two most commonly used types of environmental simulation for architecture are photography and virtual reality (Beckmann, 1998). On the one hand, photography captures images of the physical world through the action of light (Sontag, 1977). This type also includes video, which, because it is a sequence of frames (photographs), generates the illusion of movement. Similar environmental simulations can be computer generated, such as renders, which are widely used when all or part of the architectural environment to be represented does not exist (Iñarra, Juan, & Llinares, 2013). Despite the scarcity of interaction presented by photography and its variants, its visual realism and ease of use make it a valid and widely used group of formats (Rosa, 1998). In addition, photography is regaining popularity with recent developments around 360° spherical panoramic photographs (Jacobs, 2004). These photographs are not limited to a single perspective taken from a specific point, but take information about everything that surrounds that point, so that their visualisation, which requires suitable supports, offers greater interactivity: the user decides, always from the same point, which perspective to view. On the other hand, virtual reality generates computer simulations that replace the sensory information of the physical world to produce the sensation of “being there” (Steuer, 1992). This does not only involve vision, but it is possible to generate environmental simulations that stimulate other sensory channels, which is particularly interesting for enriching the experience. For example, smell has important cognitive-emotional effects in certain situations, such as stress reduction (Lehrner, Eckersberger, Walla, Pötsch, & Deecke, 2000), and hearing influences how we perceive environments (Xu, Li, & Salvendy, 2007). In terms of its general application in research, virtual reality makes it possible to independently modify variables in the same space and record their effect on the user. All at a low time and economic cost (Morganti, Carassa, & Geminiani, 2007), which is difficult to achieve in the physical environment. This makes virtual reality ideal for studying the cognitive-emotional effects of the environment (McCall, Hildebrandt, Hartmann, Baczkowski, & Singer, 2016).

2.2.1.2. Devices

The environmental simulation device refers to the display used to show the environment. To classify them, it is common to refer to the immersion they offer: the degree to which the device isolates its user from the physical world (Rangaraju & Terk, 2001). Accordingly, three levels are established: 1) non-immersive devices, such as computer monitors; 2) semi-immersive devices, such as CAVEs (cave automatic virtual environment; literally a cave of screens enveloping the user); and 3) immersive devices, such as HMDs (head-mounted displays). This immersion can be particularly important, as it generates a greater sense of presence: "the feeling of being there" (Baños et al., 2004; Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015), which can be essential for the environmental simulation to generate emotional states similar to those that would be generated by the depicted environments (De Kort, Meijnders, Sponselee, & Ijsselsteijn, 2006). This is probably one of the reasons why most of the current interest lies in immersive displays (Sharples, Cobb, Moody, & Wilson, 2008). In fact, HMDs have advanced so far that they have become affordable devices in terms of usability and economy (Parsons, 2015). This growing popularisation has contributed to the fact that virtual reality is gradually being applied to more fields.

2.2.1.3. The utility of environmental simulation systems: validity and credibility

Environmental simulation systems are undergoing profound changes (de Kort et al., 2003). New formats and devices have appeared (Rohrmann & Bishop, 2002), and their use by practitioners and researchers has increased (Bishop & Rohrmann, 2003). As a result, although many studies have been developed on the simulation of environments, previous research may now be insufficient (Lange, 2011). Thus, it is essential to update them in order to incorporate advances. This objective involves studying their usefulness.

The actualisation of this knowledge about the utility of environmental simulation systems is conceptually different according to the function for which they are used. Essentially, they can serve two broad functions: as a vehicle for 1) investigating human perception; or for 2) expressing aspects of design. The first function has found affinity in environmental psychology (Sheppard & Salter, 2004). The second function, in design in general (Clipson, 1993). Thus, the study of the utility of environmental simulation systems must be approached according to the domain.

In order to study the utility of simulations in environmental psychology, the concept of "validity" is often used. This concept refers to the ability to evoke in the user a response similar to that of the represented physical environment (Rohrmann & Bishop, 2002). That is, that the simulated environment generates a cognitive-emotional effect similar to the real environment. This is based on the logic of "behavioural realism", according to which an environmental simulation is better the more similar the responses evoked by the physical and represented environments (Freeman, Avons, Meddis, Pearson, & Ijsselsteijn, 2000). In general, results from published studies show that environmental simulations tend to be successful in this regard (Villa & Labayrade, 2012). However, in addition to the outdated nature of the emergence of new environmental simulation systems, the studies present two limitations in terms of the study of the cognitive-emotional response: they do not include the psychological response (most only compare the preference response); and the neurophysiological response is not explored.

To study the utility of simulations in design, the concept of "credibility" is often used. This concept refers to the perceived quality of the representation (Buller & Burgoon, 1996). It is a complex issue, and therefore amalgamates multiple aspects. Different works have aimed to identify them comprehensively (Appleyard, 1977; Sheppard, 1689). These aspects have been synthesised by various authors (Pietsch, 2000; Radford et al., 1997) into three: 1) precision, the accuracy that allows the observer to acquire knowledge similar to that of unrestricted observation of the design; 2) realism, the generation of a close-to-real experience; and 3) abstraction, related to the detail contained in the representation. Separately, these aspects have been extensively experimented with in different cases (e.g., to study the visual communication of landscape projects: Downes & Lange, 2015), and all three together have been widely used to study common environmental simulation systems. However, although technical information on new formats and displays for environmental representation is extensive (Orland, 1993), we found no comparative studies on the independent effect of new formats or displays in terms of their credibility.

2.2.2. Neuroscience

Neuroscience studies the nervous system (Garland, 2004). On the basis that it is preset for all humans, it has provided knowledge about its functioning (Grabenhorst & Rolls, 2011; Kircher & David, 2003). Originally, neuroscience had few sources. It was limited to the examination of patients with neural lesions (Cela-Conde, Agnati, Huston, Mora, & Nadal, 2011), which has sometimes been regarded as informative anecdotes (Chatterjee, 2011). However, with the development of neuroimaging tools, which record brain responses non-invasively (Dirican & Göktürk, 2011; Ray & Oathes, 2003), it has become possible to observe the functioning of the nervous system of healthy individuals. Today they are indispensable for exploring human cognitive-emotional processes (Cela-Conde et al., 2013).

The tools to obtain these recordings are various, and cover different portions and manifestations of the nervous system. Some of the most commonly used in neuroscience applications to other disciplines, because of their relative ease of instrumentation, are: electroencephalogram (EEG), heart rate variability (HRV), and electrodermal response (EDA; also called "galvanic skin response", or GSR). EEG records voltage variations derived from ionic flow between neurons in the brain. This implies that the recordings are mostly from the most superficial areas: the cortices (Niedermeyer & da Silva, 2005). To analyse it, it is generally used to classify the signal within defined frequencies (Sanei & Chambers, 2013) - which is based on the idea that the brain is made up of different networks, each operating at its own frequency - and to establish relationships between these frequencies (Darvas, Miller, Rao, & Ojemann, 2009). Its temporal resolution can reach 1 millisecond and its spatial resolution 10 millimetres. This excellent temporal resolution allows the analysis of stereotyped fluctuations generated by specific stimuli (Picton et al., 2000). Among other applications, EEG has been used to study mental workload (Lotte et al., 2018). HRV, on the other hand, records time variations between heartbeats (Goldman, 1976). To analyse it, time domain or frequency domain studies are generally used (Berntson et al., 1997). Its measurement has been used, for example, to study stress (Kim et al. 2018). Another tool is EDA, which records variations in the electrical properties of the skin as a consequence of sweat (Boucsein, 2012). Although sweat plays an important role in other bodily processes, it is also related to sympathetic activity (Dawson, Schell, & Filion, 2007), making it suitable for studying emotional arousal (Benedek & Kaernbach, 2010). For this reason, among other functions, EDA has been used to study attention (Prokasy, 2012). In addition, there are other tools. These include functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), electromyography (MEG), pupillometry, and eye-tracking. Given the complexity of the nervous system, all these tools are insufficient to fully explain its functioning. Nevertheless, they provide valuable information about its underlying processes.

2.2.3. Environmental simulation and neuroscience, combined

Environmental simulation and virtual reality can be combined (Hemeida & Mostafa, 2017; Riva, 2003). This allows environments to be presented while taking neurophysiological recordings from the user (Bohil, Alicea, & Biocca, 2011; Cho & Kim, 2017; Ergan, Radwan, Zou, Tseng, & Han, 2019; Merril, 1997; Radwan & Ergan, 2017). Synergy that is attractive for both clinical research (Tarr & Warren, 2002) and architecture (Jelić, Tieri, De Matteis, Babiloni, & Vecchiato, 2016). In this sense, it is increasingly being used in more and more studies to investigate the psychological (Pasqualini, Llobera, & Blanke, 2012) and neural bases of different aspects involved in how humans relate to the space around them (Sanchez-Vives & Slater, 2005). This tandem of tools allows us to evaluate the cognitive-emotional dimension of architecture from a new perspective (Chiamulera et al., 2017). However, there is still little practical work focused on improving architectural design through the use of neuroscience and its recording or neuroimaging technologies.

2.2.4. Neuroarchitecture

Neuroscience is being incorporated into the study of architectural experience (Linaraki & Voradaki, 2012). As with the basic approaches, its incorporation into the design and study of architecture, encouraged by the need to generate scientific knowledge, has been gradual. One of the most explicit early formulations of the incorporation of neuroscience knowledge into architecture was that of Neutra (1954). He argued that architecture should be oriented to meet the neurological needs of its users, incorporating available research into the development of architectural designs: "If we really want to adjust the architecture of the built environment to life, and thus place it on a physiological basis, we must take the decisive step and transcend the abstractions of Euclidean geometry". An approach which, although it was based on principles which at the time were not completely proven and not so easily extrapolated to the practice of architecture, was difficult to discredit. It would take years for this knowledge to become accessible to architects. According to certain authors (Robinson & Pallasmaa, 2015), the milestone could be marked by the publication of "The Embodied Mind" (Varela, Thompson, & Rosch, 2016). In this work, the authors coined the term "neurophenomenology", trying to reconcile the scientific view with experience (Vijayan & Embi, 2019). Indistinctly, today there is less hesitation about whether neuroscience can help us understand how we perceive and are emotionally influenced by space (Sternberg & Wilson, 2006).

The derived discipline is often referred to as "neuroarchitecture" (Chiamulera et al., 2017). Two strands stand out in the exploration of the neuroscientific basis of architecture: the design process, and the experience of architecture (Arbib, 2015). The first line (design process) has been widely developed in art in general, and has made progress in the field of architecture. For example, approaches on how to incorporate this knowledge into the design process (Banasiak, 2012; Edelstein & Sax, 2014; Manganelli et al., 2012). The second line (experience of architecture), amalgamates aspects of design. The most frequently studied are: orientation, whose research has direct relevance for improving navigation strategies (Napieralski et al., 2014b); light, addressed from both aesthetic and health-centred perspectives (Edelstein, Doctors, et al., 2008; Ellis, Gonzalez, & McEachron, 2013); and acoustics, where a relationship has been found between noise and various cognitive-emotional consequences in humans (Ising & Raun, 2000). The results support the usefulness of this novel approach to the cognitive-emotional dimension of architecture (Chow, 2015; Kayan, 2011). However, although neuroscientific research is extensive and rigorous, neuroarchitecture is emerging (Dance, 2017). Efforts are fragmented and a common framework has not been established. The novel and complex nature of neuroarchitecture makes it important to review its progress.

02 Objetivos

El objetivo general de la presente Tesis Doctoral es contribuir, a nivel teórico y práctico, en la investigación y diseño de la dimensión cognitivo-emocional de la arquitectura (aquella que se refiere a sus efectos en la valoración de la información y en las reacciones adaptativas de los usuarios), considerando el conjunto de aproximaciones a dicha dimensión: las tradicionales (la geometría, la fenomenología del espacio, la geografía de la experiencia, la filosofía, y la psicología) y las nuevas (la neurociencia y la simulación ambiental). Este objetivo está dividido en cinco sub-objetivos (SO), abordados por las investigaciones recogidas en los capítulos 3 a 7.

SO1. Examinar el estudio de la dimensión cognitivo-emocional de la arquitectura, desde una perspectiva que incorporase tanto las aproximaciones tradicionales como las aproximaciones nuevas. Este objetivo específico implica una revisión bibliográfica contextualizada y crítica.

Motivación: La novedosa y compleja naturaleza de la neuroarquitectura, hace que sea importante revisar sus avances. De manera previa, no existía una revisión contextualizada de la aplicación de la neurociencia a la arquitectura para estudiar su dimensión cognitivo-emocional, ni una clasificación de los efectos de distintas variables (objetivas, de diseño; y subjetivas) de acuerdo a la literatura de las distintas aproximaciones.

SO2. Estudiar la utilidad en psicología ambiental de los principales sistemas de simulación ambiental con los que se cuenta para presentar entornos de manera realista. Este objetivo específico involucra la evaluación de distintos formatos (fotografía, panorama 360º, y realidad virtual) mostrados a través de soportes inmersivos.

Motivación: La validación de los nuevos sistemas de simulación ambiental es una cuestión fundamental para su incorporación en estudios de psicología ambiental. De manera previa, para su validación no se había profundizado en la respuesta psicológica ni se había incorporado la respuesta fisiológica.

SO3. Estudiar la utilidad en diseño de los principales sistemas de simulación ambiental con los que se cuenta para abordar el proyecto de arquitectura. Este objetivo específico involucra la evaluación de distintos formatos (fotografía, panorama 360º, y realidad virtual) mostrados a través de distintos soportes (monitor de ordenador, y casco de realidad virtual).

Motivación: Los estudios de credibilidad sobre los nuevos sistemas de simulación ambiental son de importancia para su incorporación en el proceso proyectual. De manera previa no se contaba con un análisis combinado de los nuevos formatos y soportes.

SO4. Explorar los beneficios de combinación de la metodología cuantitativa de la semántica diferencial y la metodología cualitativa del focus group, propias de las aproximaciones tradicionales, para identificar directrices de diseño centradas en satisfacer las necesidades cognitivas-emocionales de los usuarios.

Motivación: Las sinergias de combinar ambas herramientas han sido poco exploradas en diseño arquitectónico. Su aplicación en el contexto de las salas de neonatología, ofrece una oportunidad para obtener directrices de diseño específicas con las que previamente no se contaba.

SO5. Explorar los beneficios de combinar herramientas de simulación ambiental y de registro neurofisiológico, propias de las aproximaciones nuevas, para cuantificar el efecto cognitivo-emocional de variables de diseño de distinta modalidad sensorial de manera objetiva y a tiempo real, y su correlación con las respuestas psicométricas.

Motivación: La combinación de ambas herramientas ha sido poco utilizada en trabajos prácticos enfocados en mejorar el diseño arquitectónico. Su aplicación en el contexto de las salas de espera, ofrece la posibilidad de cuantificar -objetivamente y a tiempo real- el efecto concreto de algunas estrategias conocidas de diseño.

02 Objectives

The general objective of this Doctoral Thesis is to contribute, at a theoretical and practical level, to the research and design of the cognitive-emotional dimension of architecture (which refers to its effects on the valuation of information and the adaptive reactions of users), considering the set of approaches to this dimension: the base ones (geometry, the phenomenology of space, geographical experience, philosophy and psychology) and the new ones (neuroscience and environmental simulation). This objective is divided into five sub-objectives (SO), addressed by the research collected in chapters 3 to 7.

SO1. To examine the study of the cognitive-emotional dimension of architecture, from a perspective that incorporates both base and new approaches. This specific objective implies a contextualised and critical bibliographical review.

Motivation: The novel and complex nature of neuroarchitecture makes it important to review its advances. Previously, there was no contextualised review of the application of neuroscience to architecture to study its cognitive-emotional dimension, nor a classification of the effects of different variables (objective, design and subjective) according to the literature of the different approaches.

SO2. To study the usefulness in environmental psychology of the main environmental simulation systems available to present environments in a realistic way. This specific objective involves the evaluation of different formats (photography, 360º panorama, and virtual reality) shown through immersive devices.

Motivation: Validation of new environmental simulation systems is a key issue for their incorporation into environmental psychology studies. Previously, the psychological response had not been explored in depth nor had the physiological response been incorporated into the validation process.

SO3. To study the usefulness in design of the main environmental simulation systems available to approach the architectural project. This specific objective involves the evaluation of different formats (photography, 360º panorama and virtual reality) shown through different devices (computer monitor and head-mounted display).

Motivation: Credibility studies on the new environmental simulation systems are important for their incorporation into the design process. Previously, there was no combined analysis of the new formats and supports.

SO4. To explore the benefits of combining the quantitative methodology of semantic differential and the qualitative methodology of focus groups, typical of base approaches, to identify design guidelines focused on satisfying the cognitive-emotional needs of users.

Motivation: The synergies of combining both tools have been little explored in architectural design. Their application in the context of neonatal wards offers an opportunity to obtain specific design guidelines not previously available.

SO5. To explore the benefits of combining environmental simulation and neurophysiological recording tools, typical of new approaches, to quantify the cognitive-emotional effect of design variables of different sensory modality objectively and in real time, and their correlation with psychometric responses.

Motivation: The combination of both tools has been little used in practical work focused on improving architectural design. Their application in the context of waiting rooms offers the possibility to quantify - objectively and in real time - the effect of some known design strategies.

03
Artículo 1
Paper 1

"The cognitive-emotional design and study of architectural space: A scoping review of neuroarchitecture and its precursor approaches".

Este artículo fue publicado en la revista "Sensors" (ISSN 1424-8220). Es una revista internacional, revisada por pares (siguiendo una single-blind review) y de acceso abierto, sobre la ciencia y la tecnología de los sensores y sus aplicaciones. En concreto, forma parte del *special issue* "Advances in design and integration of wearable sensors for ergonomics". Este número especial incluye trabajos sobre aplicaciones y metodologías novedosas enfocadas a integrar información cuantitativa en la ergonomía; una disciplina que, por su cometido (diseño de lugares de trabajo para satisfacer las características de sus usuarios), se alinea con el objetivo amplio de estudiar y diseñar la dimensión cognitivo-emocional de la arquitectura. La revista "Sensors" es referente en áreas de conocimiento como la instrumentalización; estando indexada en SJR (Q1 – 0.653 en 2019, última anualidad disponible; categorías como "engineering" y "medicine") y JCR (Q1 - 3.275 en 2019; categorías "instruments & instrumentation" - 15/64, "engineering, electrical & electronic" - 77/266, y "chemestry, analytical" - 22/86).

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This paper was published in the journal "Sensors" (ISSN 1424-8220). It is an international, peer-reviewed (single-blind review), open-access journal on the science and technology of sensors and their applications. In particular, it is part of the special issue "Advances in design and integration of wearable sensors for ergonomics". This special issue includes papers on novel applications and methodologies focused on integrating quantitative information in ergonomics; a discipline that, because of its purpose (designing workplaces to meet the characteristics of their users), is aligned with the broad objective of studying and designing the cognitive-emotional dimension of architecture. The journal "Sensors" is a reference in areas of knowledge such as instrumentation; being indexed in SJR (Q1 - 0.653 in 2019, last available annuity; categories such as "engineering" and "medicine") and JCR (Q1 - 3.275 in 2019; categories "instruments & instrumentation" - 15/64, "engineering, electrical & electronic" - 77/266, and "chemestry, analytical" - 22/86).

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Abstract

Humans respond cognitively and emotionally to the built environment. The modern possibility of recording the neural activity of subjects during exposure to environmental situations, using neuroscientific techniques and virtual reality, provides a promising framework for future design and studies of the built environment. The discipline derived is termed "neuroarchitecture". Given neuroarchitecture's transdisciplinary nature, it progresses needs to be reviewed in a contextualised way, together with its precursor approaches. The present article presents a scoping review, which maps out the broad areas on which the new discipline is based. The limitations, controversies, benefits, impact on the professional sectors involved, and potential of neuroarchitecture and its precursors' approaches are critically addressed.

1. Introduction

Architecture has various effects on people. Studies have been undertaken into architectural aspects most open to objectification, for example, those related to structure, construction, and installations of buildings. There exists a broad background, with standards and norms, that supports these aspects (Williams Goldhagen, 2017). However, these are not the only factors involved. The environment also has effects on humans at the cognitive level (understood as the processing and appraisal of perceived information) and the emotional level (understood as the adaptive reactions to the perceived information); both of which operate through closely interrelated systems (Ledoux, 2008). For example, it has been found that noise and a lack of vegetation can generate stress (Glass & Singer, 1972; Ulrich, 1979), and stress associated with the built environment can even negatively affect life expectancy (Glaser & Kiecolt-Glaser, 2005). Studies on specific spaces have shown a variety of cognitive-emotional impacts, such as poorer patient recoveries in hospital rooms that lack relaxing external views of greenery (Ulrich, 1984). Thus, architectural has also cognitive-emotional repercussions.

"Designerly ways of knowing" (distinct from the best-known scientific forms of knowledge (Cross, 1982) has been, traditionally, the main way to address the cognitive-emotional dimension of architecture (Sternberg & Wilson, 2006). Through this way, which offers a great economy of means, architects have explored and exploited some of the perceptual foundations of the experience of space. However it is particularly linked to subjective issues in decision-making (Lu & Liu, 2011), whose use may result in biases (Tversky & Kahneman, 1974). This can lead to inadequate results in responding to the users' cognitive-emotional needs. Although many approaches have addressed this dimension of architecture, they have not overcome some of these intrinsic limitations and, in part because of this, have not been adopted as practical design tools.

Neuroscience studies the nervous system from different areas, some of which are promising in this respect (ANFA, 2004; Edelstein & Macagno, 2012). At a general level, the application of neuroscience to architecture is often termed "neuroarchitecture" (Metzger, 2018). Although bidirectional human-space influence, and its impact on neural activity (Northoff, 2010), is not new, the modern recording of experimental subjects' neural activity during exposure to physical and simulated environmental situations provides a framework for future design and studies. For example, neuroarchitecture has allowed researchers to study in depth some design variables that reduce the stress, previously mentioned, in hospital spaces (Higuera-Trujillo, Llinares Millán, Montañana i Aviñó, & Rojas, 2020). Accordingly, the cognitive-emotional effects of architecture have been addressed through different approaches and more recently through neuroscience. This novel, complex transdisciplinary nature of neuroarchitecture make it important to review its progress. However, although reviews have been undertaken of the application of neuroscience to other arts, such as dance (E. S. Cross & Ticini, 2012), to aesthetics (Chatterjee, 2011), to architectural aesthetics (Nanda, Pati, & McCurry, 2009), and more recently to compile findings on the effects of architecture as measured by neurophysiological recordings (Azzazy, Ghaffarianhoseini, GhaffarianHoseini, Naismith, & Doborjeh, 2020; I. Bower, Tucker, & Enticott, 2019; Karakas, T., & Yildiz, 2020; Rad et al., 2021), the authors' found no previous study that reviews the application of neuroscience to architecture (sometimes referred to as "built space") to study its cognitive-emotional dimension in a holistic and contextualised way (for which it is necessary to incorporate its precursor approaches, in a complementary way to the vision of some authors in this respect (Mallgrave, 2010)). The objective of this article is to present a scoping review of neuroarchitecture and its precursor approaches. This type of literature review is aimed at mapping the broad areas in which a discipline is based.

In this sense, it is worth highlighting the shared ground between architecture, art, and aesthetics; which means that the results of the latter two may be in some way transferable to the former (for example, much of what has been studied on colour or geometry). Tackling this type of review requires a broad and interrelated perspective, which is characteristic of scoping reviews (Pham, Rajić, Greig, & Sargeant, 2014). What is especially useful in the case of disciplines that are complex (Arksey & O'Malley, 2005) and have not previously been reviewed at this level, like neuroarchitecture.

To address this broad objective, the following sub-objectives were set: (a) to provide a global vision of related scientific production, showing the trends of the different approaches in terms of type and date of publication; (b) to expose the need to investigate the impact of architecture on people; (c) to synthesise the main precursor approaches of neuroarchitecture to study the cognitive-emotional dimension of architecture; (d) to overview the progress of tools and methods in neuroscience and virtual reality, on which the new discipline is based; (e) define the state of the art of the application of neuroscience to the field of art and aesthetics, due to its similarity with architecture; and (f) to describe the main context, lines of research, and specific results of the application of neuroscience to architecture. In addition, the current status of the discipline is discussed. Therefore, a literature review was conducted.

2. Materials and Methods

Literature reviews examine articles to provide further knowledge about topics (Helewa & Walker, 2000; Lang & Heiss, 1998). There are various types. The present work was tackled by means of a scoping review (Hanc, McAndrew, & Ucci, 2019). This strategy aligns with alternatives to present a broad perspective on complex issues involving heterogeneous sources (Slavin, 1995). In addition, this leads to highly-explanatory articles (Day, 1998) that update professionals from different fields (Hutchinson, 2007); and these updates of the state of the art are essential to support the development of the neuroarchitecture discipline. Overall, preventative measures were taken to avoid biases, using a rigorous and transparent protocol (Hutchison, 1993). Denyer and Tranfield's proposals (Denyer & Tranfield, 2009) were used to structure the methodology: (1) formulation of objectives, (2) locating studies, (3) selection of studies, (4) analysis and synthesis, and (5) the presentation of the results. All the phases are detailed (Figure 3.1). The objectives of the study are described in the "Introduction" section; the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009) for systematic reviews were followed for the location and selection of the studies.

The studies were located through searches of various sources. First, the studies were found in publishers' electronic databases (Avery index to architectural periodicals, Cogprints, Elsevier, Emerald, IEEE, NDLTD, PsycINFO, PubMed/Medline, Springer, Taylor & Francis, Urbadoc, and Wiley) and repositories (Dialnet, SciELO, Google Scholar). Second, other reference lists exist, but they contain only redundant information, including content already provided by the first lists searched: Academy of Neuroscience for Architecture (https://www.anfarch.org/research/recommended-reading), Neuroscience+Architecture (http://dilab.uos.ac.kr/neuroarch/), and International Network for Neuroaesthetics (https://neuroaesthetics.net/books, and https://neuroaesthetics.net/papers). To keep the data updated, all searches were carried out four times between 28 February, 2012 and 19 July, 2019 (see "location of studies" in Figure 3.1). The same search terms and criteria were used throughout. It is worth highlighting some aspects. Regarding terminology, due to architecture's artistic and aesthetic impacts, the following concepts were considered: (architectur* OR spa* OR urban* OR "town planning") AND (neuroscien* OR percept* OR emoti* OR cogniti* OR affect*) OR neuro?architectur*; where "*" denotes truncation and "?" any character. Three criteria were stablished: language, publication category and study type. The language criterion was that the search was to be conducted in English, Spanish, German and Italian; this involved repeating the process with translations of the various terms. The publication-type criterion was threefold; the most useful sources for literature reviews are usually peer-reviewed journals and conference papers (Saunders, Lewis, & Thornhill, 2012); reference books were added to help address sub-objectives a, b, and c. It should be noted that within these types of publications, no discard criteria were considered for indications of publisher quality. Thus, the suitability of references for this review was assessed independently throughout the selection process detailed below. The third criterion was that the studies had to be human-based; given that much neuroscientific research is animal-based, this represented a significant restriction. It should be noted that, due to the temporal diversity of the approaches involved in sub-objective c, filtering by date of publication was not applied. The bibliographic references of the works retrieved were also reviewed. Therefore, these references were not localised using the above terms and language criteria. The saturation point was assumed to have been reached when the majority of the references were found to be redundant.

The selection process followed the bibliographic search. This consisted of four sequential actions: (1) elimination of duplicates, using Excel (http://www.microsoft.com/excel) and Mendeley (http://www.mendeley.com) software; (2) screening to evaluate relevance of the titles, and to make the final decision on inclusion; (3)

abstract evaluation; and (4) full-text evaluation. Regarding the latter action, it should be noted that the criterion of "not appropriate for the review's objective" refers to information that is irrelevant or was not considered to be of quality judging by its overall content (discarding, among other references, a number of bachelor's or master's degree final projects), but was not adequately filtered at the abstract stage; and the criterion of "not original data" refers to information that is redundant, or for which more representative information has been found in another article by the same authors (Figure 3.1). All the actions were centralised, to avoid mismatches in such a comprehensive reference base. The sequence made it possible to eliminate the references that did not strictly contribute to achieving the review's objectives.

Subsequently, the information selected was analysed and synthesised. Several methods are available (Dixon-Woods, Agarwal, Jones, Young, & Sutton, 2005). The content analysis synthesis framework was selected, due to its ability to interpret content (Bryman, 2001) and adapt to the heterogeneous nature of reviews (Hsieh & Shannon, 2005). Two approaches were followed: First, to categorise and group the information we undertook a "conventional content analysis"; and, second, to recalculate and compare the information we undertook a "summative content analysis". The conventional content analysis was undertaken following Graneheim & Lundman (2004), which identified relevant categories. The summative content analysis was structured in two phases: first, through compiling the neurophysiological and design aspects; and, second, by grouping these aspects. This latter analysis resulted in summary tables. Which, by collecting the effects of different design variables, can be useful for different objectives within the design and study of the cognitive-emotional dimension of the architecture. For example: in decision making prior to experimental development (to consider variables that may influence the human response, and among other actions to choose the appropriate sample); to guide the analysis (to bring forward brain areas on which to focus data processing, among other actions); and even directly in design (given that some of these questions can be understood as design guidelines). A qualitative analysis software, Atlas.ti (https://atlasti.com), was used due to the support it offers to reviews (Thomas & Harden, 2008). Three researchers, specialists in architecture, behavioural sciences, and neuroscience, independently carried out analyses. The varied profiles of the researchers helped address the heterogeneous nature of the references and to reduce the effect of possible professional deformation. The analyses were shared and discussed until consensus was reached. This gives greater reliability to the findings (Golafshani, 2003; Hill, Thompson, & Williams, 1997). The content obtained from the analyses, which was focused on meeting the sub-objectives, was organised into appropriate sections.

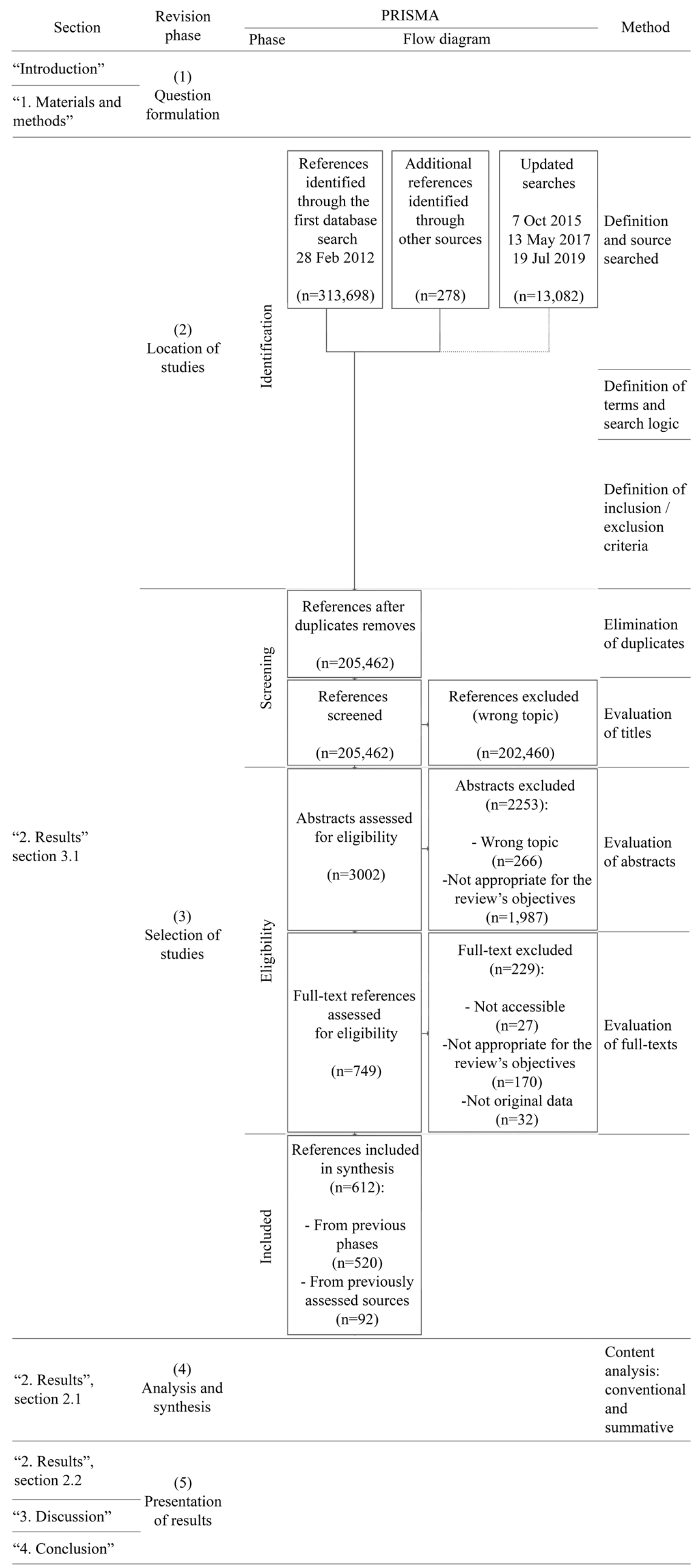


Figure 3.1. Expository and methodological structure, the PRISMA flow diagram, and its methods.

3. Results

This section synthesises the proposed sub-objectives.

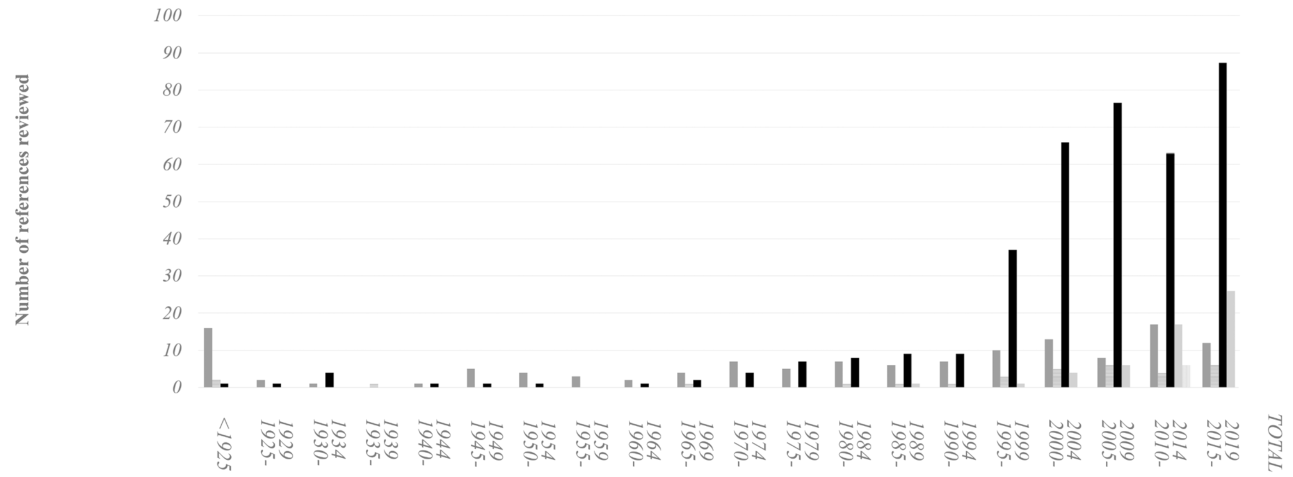
3.1. Classification of references and their descriptive analysis

The process identified 612 references that fulfilled the search criteria; 327,058 were originally identified, 289,146 from electronic databases, 37,635 from repositories, and 278 from reference lists (Table 3.1).

Table 3.1. Number of references identified in each source.

Source type	Source	Number of references
Database (N=289,145)	Springer	259,121
	NDLTD	10,962
	PubMed	5609
	Elsevier	3438
	Taylor & Francis	3209
	IEEE	2416
	Avery	1949
	Wiley	1523
	Emerald	453
	Reference Lists	278
	PsvcINFO	178
	Cogprints	9
Repositories (N=37,635)	Google Scholar	36,249
	Dialnet	711
	ScieLo	675
Reference lists (N=278)	Academy of Neuroscience for Architecture	69
	Neuroscience+Architecture	41
	International Network for Neuroaesthetics	168
	Total	327,058

Of the 205,462 references remaining after duplicates were removed, only 520 were included after a full-text search. In addition, 92 references were added following a review of the reference bibliography. Of the 612 references, 130 are books, 31 book chapters, 380 journal papers, 55 conference papers, 6 posters, and 10 of other natures. Figure 3.2 presents the proportions chronologically.



	<1925	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	TOTAL
… books	16	2	1	0	1	5	4	3	2	4	7	5	7	6	7	10	13	8	17	12	130
... book chapters	2	0	0	1	0	0	0	0	0	1	0	0	1	1	1	3	5	6	4	6	31
… journal papers	1	1	4	0	1	1	1	0	1	2	4	7	8	9	9	37	66	77	63	88	380
… conference papers	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4	6	17	26	55
… conference posters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6

Figure 3.2. Number of references included, based on type and publication date.

In terms of focus, 141 references of the 612 explicitly examine the application of neuroscience to architecture. The remaining 471 focus on the precursor approaches to the cognitive-emotional study of architectural space. Two aspects are remarkable about the neuroscience in architecture approach references. First, more references might have been expected, but this can be explained by the relatively recent emergence of the topic. Most were published after 2000 and the trend seems to indicate an increase in the next few years. Second, the high volume of recently published books. Regarding the publication dates, only first editions were considered.

In addition to references that explicitly address the issue, the others were considered relevant because they mentioned, or addressed topics related to, the review's sub-objectives.

The information in the references was categorised following the aforementioned methodology. Each reference was able to satisfy more than one category. The categories and sub-categories are shown in Table 3.2. This organisation serves as a structure for the rest of the results section (sub-objectives b to f). In this sense, Figure 3.3 provides a map of the general contents of this article.

Table 3.2. Categories and sub-categories linked to the references.

Category	Sub-category
1. The impact of architecture on human beings and directly associated research	
2. Base approaches to the cognitive-emotional dimension of architecture	2a Geometry
	2b1 Space phenomenology
	2b2 Geographical experience
	2c1 Philosophy
	2c2 Environmental psychology
	2c3 Evidence-based design
3. New architectural study and practise tools	3a Neuroscience
	3b Virtual reality
	3c Combined neuroscientific and virtual reality technologies
4. The cognitive-emotional dimension of architecture through neuroaesthetics	4a Neuroscience and psychology in art and aesthetics
5. Neuroscience in architecture	

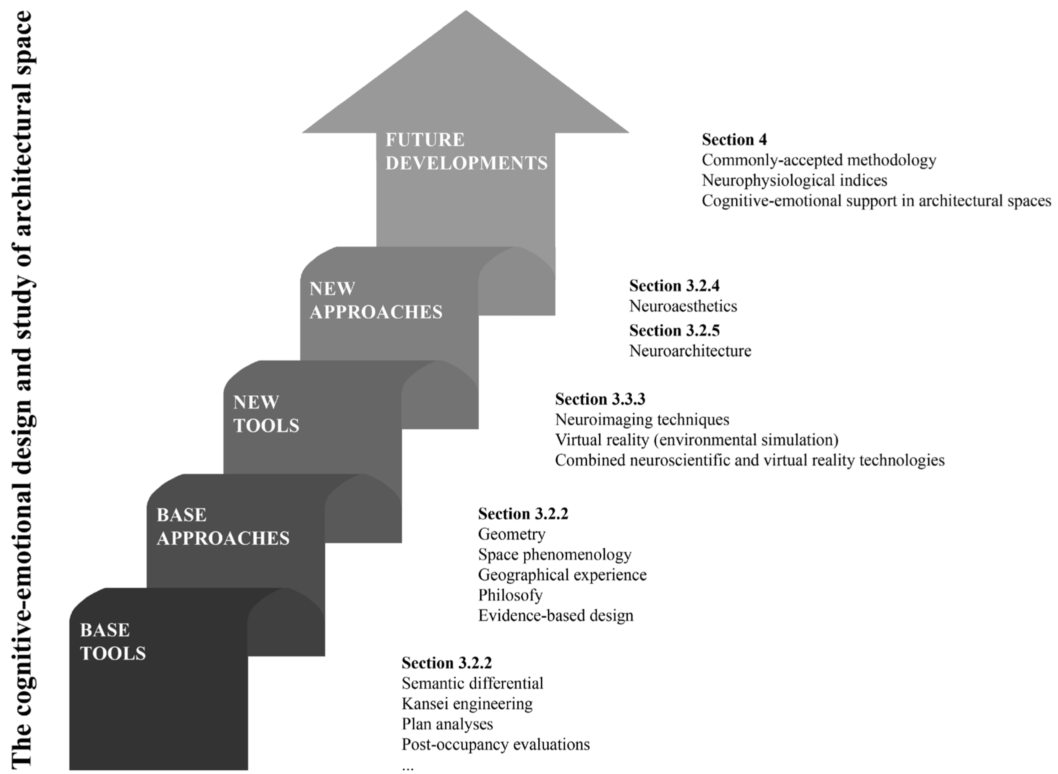
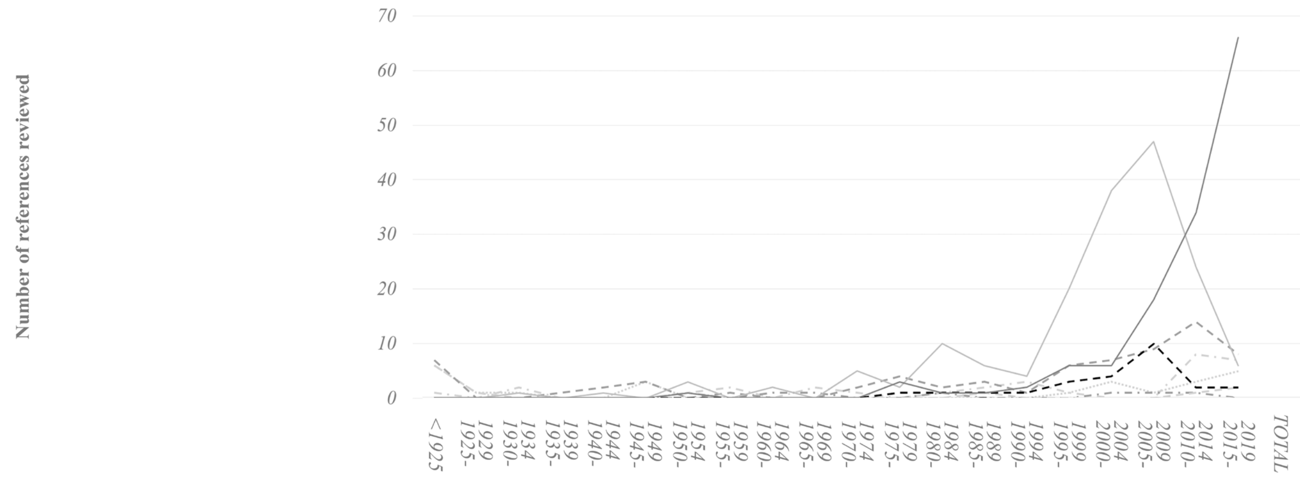


Figure 3.3. Expository structure and key-concepts map of the paper.

Figure 3.4 provides temporal information about the sub-category references relating to approaches to the cognitive-emotional dimension of architecture. The following should be noted: (1) the different approaches that have addressed the human-space relationship have enjoyed moments of greater popularity; and (2) neuroscience was applied to architecture later than to art and aesthetics. Both aspects suggest that including all the sub-categories helps address the issues that motivate this review.



	<1925	1925-1929	1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	TOTAL
Geometry	6	1	1	0	0	3	0	0	0	0	0	0	0	0	0	1	3	1	3	5	24
Space phenomenology	1	0	2	0	0	0	1	2	0	2	1	0	1	2	3	1	0	0	8	7	31
Geographical experience	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	1	1	0	6
Philosophy	6	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	2	12
Environmental psychology	7	0	0	1	2	3	0	1	0	0	2	4	2	3	1	6	7	9	14	9	71
Evidence-based design	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	4	4	9	2	2	25
Neuroscience and psychology in art and aesthetics	0	0	1	0	1	0	3	0	2	0	5	2	10	6	4	20	38	47	24	6	169
Neuroscience in architecture	0	0	0	0	0	0	1	0	0	0	0	3	1	1	2	6	6	18	36	67	141

Figure 3.4. Number of references included, grouped by the categorisation of the approaches to the cognitive-emotional dimension, and date of publication.

3.2. Holistic framework of the issue

This issue comprises various topics. Addressing it requires a holistic approach. The expository sequence follows the structure shown in Table 3.2.

3.2.1. The impact of architecture on human beings and directly associated research

The influence of architecture on humans beings that acts of spatial planning have led to the current built space (Tuan, 2007), our largest artifact (Robinson, 2011, 2015). Beyond its utilitarian character architecture has complementary cognitive-emotional impacts (Hietanen & Korpela, 2004). Architecture can both elicit brain activation and modulate genetic function (ANFA, 2005a). Consequently, changes in the environment have important impacts (Gage, 2003). Its physiological and social effects should be emphasised. At the physiological level the consequences for human development, performance, and stress are illustrative. Regarding development, a balanced environment can improve creativity (Malinin, 2014) and cognitive function (Bruer, 1997). In fact, poor environmental stimulation affects brain development (Perry, 2002). Environmental effects are not limited to growth stages. The environmental stimulation provoked by classroom design can improve students' performance through, for example, using of cold colours (Al-Ayash, Kane, Smith, & Green-Armytage, 2015) or smaller spaces. As to stress, some environmental elements -such as noise or the absence of vegetation- have been shown to have negative consequences (Averill, 1973; Glass & Singer, 1972). Among these impacts are poorer patient recovery (Kiecolt-Glaser et al., 1998) and shorter life expectancy (Glaser & Kiecolt-Glaser, 2005). On the other hand, in line with the concept of "healing environment" (Stichler, 2001), various studies have underlined the curative benefits of architecture (Pinter-Wollman, Jelić, & Wells, 2018). At the social level it has been found that, for example, the environment can promote collectivism (Kim & Kaplan, 2004), attract candidates for posts in organisations (Powell, 2003), and improve citizens' sense of belonging (Newman, 1972) and behaviour (Hollier, 1992). It should be noted that the impact of environmental effects depends on the user's sensitivity (Dijkstraa & Pieterseb, 2008), and non-architectural elements may also have effects (Aiello, Epstein, & Karlin, 1975).

Architects have been aware of this impact (Vannuci et al., 2014) and that when designing architecture, experience is designed (Nanda, Pati, Ghamari, & Bajema, 2013). As Aalto noted, humanising architecture involves "a functionalism much larger than the merely technical" (Schildt, 1997). "When I enter a space, the space enters me and transforms me" (Pallasmaa, 2018). These statements make it clear that addressing the cognitive-emotional state of the users is a transcendental function of architecture (Eberhard, 2009; Veal, 2005). Despite this, the aspects most likely to be objectified have been extensively studied, and the cognitive-emotional dimension has been less explored (Changeux, 1985; Pearson, 2005).

The fundamental limitation of this research is that the architectural design process is very complex (Powell, 1987), basically because the myriad of design solutions (the possible configurations of all design variables) makes it impossible to test them all. In addition, the problems that the design solutions try to resolve are diverse and vary over time (e.g., the individuals' needs from their houses can vary as they age). Although there has been extensive research into the built environment, which indicates that a certain level of analysis is possible, architectural design is infrequently scientifically approached. Hence, the cognitive-emotional dimension of architecture has formed only a small part of the formative content (Bermudez, Krizaj, Lipschitz, Yurgelun-Todd, & Nakamura, 2014), and the implementation of the design has been mostly based on an amalgam of practices and motivations specific to the architectural project that are part of the "designerly ways of knowing" (Cross, 1982).

With this as the main way of approaching the cognitive-emotional dimension of architecture, more of the objectives of architectural design have shifted to more tangible and easily quantifiable issues; such as those closely related to the constructive processes of buildings. What has been pointed out from different perspectives. "Architecture and the modern cities that have been built tend to be inhumane" (Meyakawa, 1965). Have we turned our space into an economic-cosmetic product that ignores our primitive codes (van Eyck, 1967)? The importance of the built environment cannot be underestimated. "Any future construction must be preceded by a profound study of the relationships between spaces and feelings" (Debord, 2003). In this sense, new tools that show the future of neuroarchitecture have been incorporated into the traditional architectural spectrum (Zeisel, 2006).

3.2.2. Base approaches to the cognitive-emotional dimension of architecture

Architectural space has been the focus of thinking and research at the cognitive-emotional level. The concept has been addressed at different times. Therefore, knowledge of these bases allows us to contextualise current developments in the application of neuroscience to architecture and to understand the context of current practice (Mallgrave, 2010). This section exposes the base approaches organized as follows: (1) geometry; (2) phenomenology of space and geographical experience; and (3) philosophy, environmental psychology, and evidence-based design. This classification acknowledges the relationships between the base approaches.

3.2.2.1. Geometric approach

Although users might not experience the exact dimensions of proportions, they will feel the underlying harmony (García Cortés, 2007). Architects have worked with geometric proportions to address the cognitive-emotional dimension of architecture. Thus, the geometric approach is a valid starting point from which to understand how architects work and establish bridges that can lead to the development of design tools (Powell, 1987).

The geometric connection between the human body and architecture has historically been addressed by two fundamental approaches, theomorphism and anthropomorphism. Theomorphism has existed at least from classical Greek architecture (Ramírez, 2003). A well-known example is the Parthenon, fundamentally based on geometric proportions. The cognitive-emotional effect of the Parthenon's geometric proportions is similar to that sought centuries later by architects such as Palladio (Palladio, 2005) and Le Corbusier (Corbusier, 2005) through a series of geometric-mathematical rules. Anthropomorphism also has a long tradition. Examples are found in the classical Roman world, such as temples based on the symmetry of the human body (Vitruvio, 2016); and, more recently, in the Renaissance and the Baroque periods, where human bodies appeared in some buildings (Filarete, 1965). However, this architecture-body metaphor has been subjected to different efforts to mathematise it, which shows that these two approaches are not mutually exclusive. For example, Alberti's attempts to humanise space based on the geometry of the human body (Alberti, 1988, 1998). This line was exploited with Rationalism, as opposed to speaking architecture (Durand, 2000), which led to works by Klint (1930), Bataille's anthropomorphic architecture (Bataille, 1929), the organic architecture of Zevi (1957), the close association with daily human needs of Smithson (2004), and Niemeyer's (1998) and Mollino's designs directed towards life actions (Mollino & Vadacchino, 1948).

Many of these geometric concepts are recurring. On the one hand, geometrical relationships found to be aesthetic, such as the nine-square pattern (Ruggles, 2017), or the golden section, have been validated experimentally (Höge, 1995), the latter even using virtual reality (Franz, von der Heyde, & Bülthoff, 2005) and neuroscientific bases (Mehta, Lee, & Shafle, 2012). On the other, the new attempts to quantify geometric properties to capture the cognitive-emotional dimension of architecture are worthy of mention. Among these are isovist analysis -the volume of space visible from a given point in space (Dzebic, Perdue, & Ellard, 2013)-, and the application of artificial intelligence to distinguish formal categories, based on different features (Banaei, Ahmadi, & Yazdanfar, 2017). The recent mathematical-geometric analysis of architectural images is also noteworthy (Cavalcante et al., 2014; Coburn et al., 2019; Kacha, Matsumoto, Mansouri, & Cavalcante, 2013), through its use in architectural spaces of spatial metrics, such as edge density (number of straight and curved edges), fractal dimension (visual complexity), and entropy (randomness); and colour metrics, such as hue (the dominant wavelength), saturation (the intensity of colour), and brightness (the darkness of colour). Hence, the geometric approach has not been abandoned.

3.2.2.2. The phenomenology of space and geographical experience approach

Phenomenology is the study and description of phenomena as experienced through the senses in the first person. It is based on phenomena capable of being felt (Husserl, 2012). Architects have found affinities with this approach, probably because it is related to intuition.

One of the first studies into subjective space was Husserl's exposition of his ideas about the external world (Husserl, 1913). Heidegger continued with these influences in "Being and Time" (Heidegger, 1998), addressing the spatiality of humans and the concept of "Stimmung" (or state of mind), which is fundamental for understanding subjective space: "being impregnated by an environment". Some of the first explicit formulations were made by Dürckheim (1932) and Minkowski (1967), focusing on vital space. Some of the advances were compiled in "Situation" (Buytendijk, 1954). Later, the concepts of hodological space and distance -the way in which people evaluate the routes, the preference being based on subjective and objective influences- were introduced by Lewin (1934), and developed by Sartre (2016). Bachelard (2005) developed his space poetics, a concept widely embraced in the theory of architecture, that seeks to explain the human being's relationship with the world through poetic images. Rasmussen (2004) presented a phenomenological vision of architecture which exemplified the syncretism between phenomenology and architecture. Bollnow (1969) presented concepts involved in subjective space: "[...] Unlike mathematical space, subjective space is characterised by its lack of homogeneity." This is because subjective space derives from the human's relationship with space. This has led, even, to suggestions that objective space does not exist, because it is always perceived (Lacoste, 2003). These concepts (objective space and subjective space) have, indeed, been embraced by many authors in different approaches to the cognitive-emotional dimension of architecture. At the same time, the concepts have been developed in geographical experience (Buttimer & Seamon, 1980), and have practical applications in urban planning (Gutiérrez Plaza & Somoza Medina, 2006). Lynch work, which shows the influence of environmental psychology on the phenomenology of space (Lynch, 2008), is representative of its beginnings (Vara Muñoz, 2010). More recently, Pallasmaa, influenced by previous authors, examined the phenomenology of space in architecture (Pallasmaa, 1985, 1993) that claimed that architecture takes account of the human biological dimension. Pallasmaa's line here is shared with Holl and Pérez-Gómez (Holl, Pallasmaa, & Pérez-Gómez, 1994; Pérez-Gómez, 2015). The phenomenology of space has more recently gained momentum under new approaches based on the concept of atmospheres (Böhme, 2017; Schmitz, Müllan, & Slaby, 2011): quasi-things, without discrete or visible limits, that exist because of our emotional encounter with the environment (Griffero, 2010; Griffero & Moretti, 2018). Thus, the phenomenology of space and geographical experience have not been neglected.

3.2.2.3. The philosophy, environmental psychology, and evidence-based design approach

Psychology addresses the behaviours and mental processes involved in experience (Gross, 2015). Its focus on space is "environmental psychology" (Bones & Secchiaroli, 1995; Kaminski, 1976). Environmental psychology takes phenomenology as one of its substrates (Kruse & Graumann, 1987), hence it is sometimes difficult to distinguish them. Nor is it easy to discern the philosophical origins of environmental psychology (Pol, 1988).

It is illustrative to consider philosophical milestones. Burke presented an influential philosophical exposition on aesthetics, theorising about beauty through psychophysiological concepts (Burke, 2003). Burke's ideas attracted the attention of Kant, who identified space and time as the mental structure of things that we know (Kant, 2004). A series of works contributed to the expansion of psychology. Among these are: Zeising, who combined geometry and psychology (Zeising, 2015); art, physiology, and emotion were linked by Friedrich Theodor Vischer (Vischer, 1866) and Robert Vischer (Vischer, 1994) (who coined the term "einfühlung": aesthetic empathy, the process through which humans project their emotions onto objects); Fechner, who combined physiology and psychology (Fechner, 1876); Wundt (2009) and Stumpf (1873), who combined psychophysiology and philosophy. Later, Wertheimer, Koffka, and Köhler (students of Stumpf), established gestalt psychology (Ash, 1998). Gestalt psychology established principles, or laws (Sternberg, 1996), about the organisation of scenes (Table 3.3). Many design professionals, including architects, have often embraced these principles. It is noteworthy that Koffka (2014) studied the organisation of the visual field, and Köhler developed the concept of "isomorphism" -the correlation between experience and neural activity (Köhler, 1920)- and experience as a sensory sum (Köhler, 1992). At this historic point, the connections between psychology and neuroscience were evident. Although subsequent studies may have rejected some of these findings, some have been accepted and the works themselves have been recognised as meritorious (Sheynin, 2004).

Table 3.3. Compilation of some gestalt principles.

Principle	Trend
Totality	The whole is different from the sum (the perception of entities depends on their context)
Dialectic	Establishing entities separate from their background
Contrast	The entity is better perceived if there is marked contrast with its background
Hierarchy	The greater the importance of an entity the more hierarchical its parts are
Birkhoff	Entities with multiple axes are more positively perceived

Principle	Trend
Symmetry	To perceive features as symmetrical, around a centre point
Multistability	Perceiving different entities from the same ambiguous experience
Reification	To assign more information to a perception than is contained in the base stimuli
Completion	To perceive forms as closed when they are not
Closure	To perceive closed forms as better
Continuity	To integrate elements of entities, if they are aligned
Good Gestalt	To integrate elements of entities, if they form a regular pattern
Invariance	To recognise entities, regardless of transformations
Proximity	Group entities based on their proximity
Similarity	Group entities based on their similarities
Experience	To categorise stimuli based on previous experiences

One of the advantages of environmental psychology for addressing the cognitive-emotional dimension of architecture is its evaluation instruments. Semantic differential is among the most used (Osgood et al., 1957). This is based on the idea that a concept can acquire meaning when a sign (word) provokes the response associated with what it represents, which suggests the existence of an underlying structure. The models of Küller (1972, 1980, 1991) and Russell & Mehrabian (1977), which described the affective-emotional states elicited by the experience of space, should be highlighted. One of its first applications was in architecture (Gifford, Hine, Muller-Clemm, Reynolds, & Shaw, 2000). More recently it has been used to quantify the relative importance of different design variables (Ergan, Shi, & Yu, 2018). In this respect, it should be noted that some variables, such as the presence of vegetation and illumination, have been much examined, but others, such as those focused on spatial geometry, have been less explored (probably, in part, because of the experimental difficulty involved in modifying them in a controlled manner). Semantic differential has also been used in the context of Kansei engineering, a product development method that translates the underlying structure into configurations of variables (Nagamachi, 1995). It has been applied in different contexts, including the architectural (Higuera-Trujillo, Montañana i Aviñó, & Llinares Millán, 2017; Kinoshita et al., 2006; Sendai, 2011) and urban planning (Kinoshita et al., 2006; Llinares et al., 2013).

A more practical application of the tools available in environmental psychology is an evidence-based design (EBD) approach: "the process of basing decisions about the built environment on credible research" (Levin, 2008). Its origins can be found in the medical field, as an extension of evidence-based medicine (Edelstein, Doctors, et al., 2008) to architectural design (Ulrich, 2006). Illustrative are the plan analyses (van der Voordt, Vrielink, & van Wegen, 1997) and post-occupancy evaluations (Sherman, Varni, Ulrich, & Malcarne, 2005). Since Ulrich demonstrated the influence of environment on patient recovery (Ulrich, 1984), it has been widely applied in healthcare spaces (Devlin & Arneill, 2003; Iyendo, 2016; Salonen et al., 2013; Ulrich, 1999; Ulrich et al., 2008; Zhang, Tzortzopoulos, & Kagioglou, 2019). One of the reasons that EBD is so widely used is that it is available to any organisation (Banasiak, 2008). Various aspects have been studied. For example, reducing pain (Malenbaum, Keefe, Williams, Ulrich, & Somers, 2008) and stress (Ulrich, Zimring, Quan, & Joseph, 2006), improving rest (Aaron et al., 1996), spatial orientation (Carpman, Grant, & Simmons, 1990), wandering (Algase, Beattie, Antonakos, Beel-Bates, & Yao, 2010), privacy and security (Barlas, Sama, Ward, & Lesser, 2001), social cohesion (Chaudhury, Mahmood, & Valente, 2005), overall well-being and satisfaction (Leather, Beale, Santos, Watts, & Lee, 2003), and the design of children-tailored environments (Dobkins & Heyman, 2013). Table 3.4 compiles effects generated by different design variables, according to different studies both in environmental psychology and EBD.

Table 3.4. Effects generated by variables or aspects of architectural design frequently studied in the environmental psychology and EBD approach.

Design variable	Effect
Ceiling height	High ceilings inspire freedom, low ceilings calm (Meyers-Levy & Zhu, 2007).
	High ceilings generate greater creativity and feelings of comfort (Taher, 2008).
	Ceiling height positively affects wayfinding (Erkan, 2018)
Presence of vegetation	Vegetation reduces stress and anxiety (Ulrich, 1979).
	In parks, pleasure increases based on tree density, and arousal with weed density (Hull IV & Harvey, 1989).
	Biophilia hypothesis: preference for natural forms (Joye & De Block, 2011; Kellert, Heerwagen, & Mador, 2008).
	Attention restoration theory: natural environments are restorative. Their restorative characteristics are "fascination", "being away", "coherence", and "compatibility" (Kaplan & Kaplan, 1989).
Complexity	Preference for moderate levels of complexity, similar to a savannah environment (Joye, 2007).
	Prospect-refuge: preference for natural and built environments which offer visual control of the environment and places to hide (Appleton, 1975; Dosen & Ostwald, 2016; Hildebrand, 1999).
Illumination	Colour temperature and illuminance are interrelated with comfort (Kruithof, 1941).
	Natural light reduces hospital stays (Park, Chai, Lee, Moon, & Noh, 2018).
	Light and form are interrelated: walls and ceilings influence the perception of brightness; a room appears larger when it receives more indirect light (Houser, Tiller, Bernecker, & Mistrick, 2002).

Design variable	Effect
Illumination	Mood valence and cognitive performance alter based on light parameters: colour temperature with less negative effect on mood, improved cognitive performance; the combination of colour temperature and illuminance with better evaluation in mood, improved cognitive performance (Knez, 1995).
	Emotional states affect the perception of brightness (Zhang, Zuo, Erskine, & Hu, 2016).
Colour	Extracted at an early stage of visual processing (Zeki, 1980)
	Wide variety of effects on aesthetic preferences (Maffei & Fiorentini, 1995).
	Hue and saturation are related to emotional state (Hogg, Goodman, Porter, Mikellides, & Preddy, 1979).
	Warm tones have higher arousal values, and colder tones lower (Yildirim, Hidayetoglu, & Capanoglu, 2011).
Use	The use to which a space is put influences its psychological evaluation (Chamilothori et al., 2019).
Coherence	In natural settings, the coherence of a setting with wooden furniture is significantly greater than a setting with metal furniture, but significantly less than a setting without furniture (Pals, Steg, Dontje, Siero, & van Der Zee, 2014).

3.2.3. New tools in architectural research and practise

The base approaches, in general, have two limitations: (1) the validity of the selected stimuli; and (2) the applicability of the evaluations. Regarding the stimuli, although representations may be valid (Bateson & Hui, 1992), they are limited. For example, photos and videos, frequently used, offer little interactivity. This reduces virtual immersion (Ijsselsteijn et al., 2000) and impoverishes the experience. When environmental simulation differs from reality results can be distorted. Moreover, these stimuli do not allow environmental parameters to be controlled. Regarding evaluations, self-reports are prone to bias (Schwarz & Strack, 1999), as they record only the conscious aspects of human responses. This is important, given that most cognitive and emotional processes occur at the unconscious level (Zaltman, 2003). Taking these points into account, the results must be contextualised.

New approaches to the cognitive-emotional dimension of architecture, try to overcome these limitations. New research tools provide: (1) artificial stimuli that are more similar to physical, real stimuli (in the represented spaces); and (2) new, more objective evaluations of cognitive-emotional responses. Virtual reality (VR) is frequently used to provide stimuli. VR simulates environments in a realistic, immersive, and interactive way (Rheingold, 1991) under controlled laboratory conditions (Vince, 2004). As to evaluation, neuroscience and its related technologies allow researchers to record and interpret human behavioural, physiological and neurological reactions (Winkielman et al., 2001), providing high levels of objectivity (Poels & Dewitte, 2006) and continuous monitoring (Reinerman-Jones et al., 2010, 2013). Although neuroscientific techniques have been available for decades, their application is currently expanding.

3.2.3.1. Neuroscience

Neuroscience studies the brain and nervous system (Kandel, 2013). On the basis that normal human brains are quite similar, neuroscience has provided insights into the functioning of the nervous system (Grabenhorst & Rolls, 2011; Kircher & David, 2003). Resorting to the brain is starting from the root (Dewey, 2008). Neuroscience has different areas of expertise (Breedlove & Watson, 2019). This has allowed its results, methodologies, and tools to also have an implication on issues directly related to other disciplines. For example, cognitive neuroscience, behavioural neuroscience, neurophysiological neuroscience, and sensory neuroscience shed light on perception in general (Solms & Turnbull, 2002) and on space in particular (Clément & Reschke, 2010). Given neuroscience's applicability to architecture (de Paiva, 2018), the discipline can contribute to quantifying architecture's impact on humans (ANFA, 2005b; Nold, 2009). Thus, designs can be produced that contribute to their users' quality of life (Eberhard, 2007; Edelstein, 2006b).

However, human nervous system studies have had few avenues to explore human brain function. They have generally been limited to examining patients with neural injuries or suffering from neurodegenerative diseases (Cela-Conde et al., 2011); studies into the effects of neuronal injuries on art production have followed this approach (Zaidel, 2005). For example, it has been found that frontotemporal dementia changes musical taste (Boeve & Geda, 2001), that damage to the amygdala impairs the identification of sad music (Gosselin, Peretz, Johnsen, & Adolphs, 2007), and that damage to one hemisphere causes spatial neglect on the opposite side in drawings (Blanke, Ortigue, & Landis, 2003; Cantagallo & Sala, 1998; Halligan & Marshall, 1997). Paradoxically, neuronal injuries can sometimes improve artistic skills (Chatterjee, 2006, 2009; B. Miller & Hou, 2004). Due to the paucity of this form of study, they have sometimes been considered "informative anecdotes" (Chatterjee, 2011), and the clearest conclusions have only been able to be drawn after the joint analysis of cases (Bogousslavsky, 2005).

Neuroimaging techniques open new paths. Based on the non-invasive recording of brain responses (Dirican & Göktürk, 2011; Ray & Oathes, 2003), they allow observation of the responses of healthy individuals under controlled conditions. From their first applications to art, studies have made substantial progress (Fairhall & Ishai, 2008; Ishai, Fairhall, & Pepperell, 2007). These techniques are today essential in the exploration of the neural processes involved in art generation and appreciation. Various tools are used to obtain the recordings (Bagozzi, 1991) from the central (CNS), the autonomic (ANS), and the somatic (SNS) nervous systems.

The CNS is made up of the brain and the spinal cord. The tools most commonly used to study CNS functions in living humans are functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and magnetoencephalography (MEG). fMRI measures neuronal activity indirectly by detecting changes in magnetic properties related to blood flow (Soares et al., 2016). Although its temporal resolution is poor, fMRI yields better spatial resolution and deep structure identification than other methods. fMRI has been used to study aspects such as memory

(Thibault, MacPherson, Lifshitz, Roth, & Raz, 2018). EEG measures electric field fluctuations due to the ionic currents generated by neuronal activity in the brain, mainly the cortical areas because they are the most superficial (Cohen, 2017). The analysis of the recordings generally involves the classification of power spectral densities within defined frequency bands -on the basis that the brain is made up of different networks that operate at its frequency- and relationships between these networks (Mohammadi, Frounchi, & Amiri, 2017). The high temporal resolution of EEG allows the analysis of stereotyped fluctuations generated by discrete stimuli (Yao et al., 2019). EEG has been used to study, for example, mental workload (Lotte et al., 2018). In contrast, MEG measures the magnetic fields generated by the ionic current (Boto et al., 2018). Although its infrastructure has drawbacks (MEG equipment is not wearable or portable), the skull and scalp distort the magnetic fields less than the electric. This advantage makes MEG a powerful tool for exploring the functions of deeper cellular structures, such as the hippocampal's role in cognition (Pu, Cheyne, Cornwell, & Johnson, 2018). In parallel, it is possible to stimulate brain areas using transcranial magnetic stimulation (TMS), a technique used in various fields (Valero-Cabré, Amengual, Stengel, Pascual-Leone, & Coubard, 2017).

The ANS, part of the peripheral nervous system, controls involuntary actions. The tools most commonly used to study ANS function monitor electrodermal activity (EDA; also called Galvanic Skin Response, or GSR), heart rate variability (HRV), and pupillometry. EDA measures variations in electrodermal properties, particularly electrical conductivity (Boucsein, 2012). Sudomotor activity is related to sympathetic nervous system activity (Dawson et al., 2007), so it is appropriate for tracking arousal (Benedek & Kaernbach, 2010). EDA has been used to study, for example, attention (Raskin, 1973). HRV measures the variation in time between heartbeats (Goldman, 1976). HRV measurements are generally grouped into time-domain and frequency-domain, both having clinical and cognitive-emotional significance (Berntson et al., 1997). It has been used to study issues such as stress (Kim et al., 2018). Pupillometry is the measurement of the diameter of the pupil of the eye (Laeng, Sirois, & Gredebäck, 2012). Although pupil diameter is directly affected by light level, it has also been related, for example, to arousal (Hess & Polt, 1960) and cognitive load (Granholm & Steinhauer, 2004). While ANS activity has been considered insufficient to study the nuances of emotion (Di Dio & Gallese, 2009), more recently has been favoured (Kreibig, 2010).

The SNS is the part of the peripheral nervous system associated with voluntary movement. Eye tracking and electromyography (EMG) are commonly used tools. Eye tracking is the measure of gaze movement (Duchowski, 2003). Eye movements, to an extent, identify the focus of our attention (voluntary and involuntary), and are influenced by cognitive-emotional states (Schofield, Johnson, Inhoff, & Coles, 2012). Various metrics are used to measure eye movements, based on the parametrization of the movements (Holmqvist et al., 2011). For example, eye tracking has been used to study engagement (Meißner & Oll, 2019). EMG measures the electrical activity of the muscles (Kamen, 2004). To measure facial expressions related to emotion (Ekman & Friesen, 1971), recordings are usually made of the corrugator supercilii (Sato, Fujimura, & Suzuki, 2008) and the zygomaticus major (Larsen, Norris, & Cacioppo, 2003), muscles strongly influenced by emotional valence (Wolf et al., 2005). Thus, EMG has been frequently used to study basic emotions (Calvo & Nummenmaa, 2016). There is, in addition, automatic image-based facial expression recognition (facial coding). Some architectural studies have applied physical eye tracking (Andreani & Sayegh, 2018; Kwon & Kim, 2018; Suurenbroek & Spanjar, 2018) and eye tracking simulated by software (Sussman, 2018), and facial coding (Chalup, Hong, & Ostwald, 2010).

Given the complexity of neural activity, these tools are insufficient to fully explain it. But they offer information about its bases and are compatible with other approaches. They make a contribution that, in architecture, recalls the optimism that Frampton attributed to the technique to "replace the devalued motives [...] of our environment and, turn it into an authentic place" (Frampton, 2005).

3.2.3.2. Virtual reality

Environmental simulations are representations of actual environments (de Kort et al., 2003). There are different types (Lange, 2001). VR generates interactive real-time computer representations that replace the visual information normally provided by the physical world and create the feeling of "being there" (Steuer, 1992). It is possible, though seldom done, to create virtual representations using other sensory channels. This type of stimulation is especially interesting. For example, head transfer function (a response to how a sound emitted from a point is received after the sound arrives at the listener) is involved in how we perceive physical and virtual environments (Xu et al., 2007); hapticity plays an important role in the supramodal experience of architecture (Papale, Chiesi, Rampinini, Pietrini, & Ricciardi, 2016); and smell has important cognitive-emotional effects in certain situations, such as stress reduction (Higuera-Trujillo et al., 2020).

Various devices are used to reproduce VR formats. It is common to classify them according to immersion: the degree to which the hardware isolates the user from the physical world (Rangaraju & Terk, 2001). Thus, there are non-immersive devices, such as desktop PCs; semi-immersive devices, such as the cave automatic virtual environment (CAVE); and fully-immersive devices, such as head-mounted displays (HMDs). Greater immersion generates a greater sense of presence, that is, the user's perceptual illusion of non-mediation (Baños et al., 2004; Slater & Wilbur, 1997). Greater presence also involves the allocation of more brain resources for cognitive/motor control (Slobounov, Ray, Johnson, Slobounov, & Newell, 2015). Although non-immersive devices inherently offer the advantage of collaborative viewing (Churchill & Snowdon, 1998), the majority of current interest focuses on the other two types of device and, indeed, HMDs are now within reach in terms of usability and affordability (Parsons, 2015). This increasing popularisation has contributed to VR being used in other fields.

In architecture VR has given rise to an explosion of applications (Paranandi & Sarawgi, 2002). VR allows us, to modify variables in the same space in isolation and record human interaction with the environment, quickly and at low cost (Morganti et al., 2007). VR, thus, is an optimal tool for evaluating human responses to architecture (McCall et al., 2016), at both behavioural and neurophysiological levels (Díaz Levicoy, 2014; L. Zhang et al., 2010) and even its cartographic representation (Higuera-Trujillo et al., 2016). For example, it has been used to study relationships between experience and space variables (Hobbs, Hunker, Demircay, Rodriquez, &

Issa, 2014), facilitate design decision-making (Frost & Warren, 2000), and assess accessibility (Cazorla, Fiel, Sanjuán, & Miralles, 2011; Stevenson et al., 2014) and orientation inside buildings (Conroy, 2001), including in emergency situations (Smith & Trenholme, 2009). Thus, VR provides knowledge beyond that provided by the physical world.

The interactivity inherent in VR gives rise to a fundamental aspect that should be addressed, navigation. Two components of navigation are usually discussed, wayfinding and travel (LaViola, Kruijff, McMahan, Bowman, & Poupyrev, 2017). Wayfinding is the cognitive process of establishing a route (Bliss, Tidwell, & Guest, 1997; Napieralski et al., 2014). It has been suggested that wayfinding performance in virtual environments is poorer than in physical environments (Richardson, Montello, & Hegarty, 1999; van der Ham, Faber, Venselaar, van Kreveld, & Löffler, 2015). The travel component, related to the task of moving from one point to another, has been found to be strongly affected by the navigation metaphor used to perform the navigation. Many navigation metaphors, classified as physical or artificial, are available. Physical metaphors are varied. For example, room-scale based metaphors, such as real walking inside a physical space; this is the most naturalistic metaphor but is highly limited by the physical tracked area (Bozgeyikli, Bozgeyikli, et al., 2016); motion-based metaphors, such as walking-in-place, which is a pseudo-naturalistic metaphor where the user performs virtual locomotion, while remaining stationary (e.g., moving the hands), to navigate (Tregillus, Al Zayer, & Folmer, 2017); or redirected walking, a metaphor where users perceive they are walking while they are unknowingly being manipulated by the virtual display, which allows navigation in an environment larger than the physical tracked area (Nescher, Ying-Yin Huang, & Kunz, 2014). Artificial metaphors facilitate direct movements using joysticks, keyboards, or similar devices (Nabiyouni, Saktheeswaran, Bowman, & Karanth, 2015). Among these are teleportation-based metaphors, which allow users instantaneous movement to a selected point (Bozgeyikli, Raij, Katkoori, & Dubey, 2016). There is no consensus as to which is the most appropriate (Lee, Ahn, & Hwang, 2018). Since navigation can radically condition space perception and, therefore, subsequent human responses, it is a key aspect that needs to be considered.

However, VR does have some problems. These are generally of a technical nature, such as the previously discussed navigation (Hendrix & Barfield, 1996; Kimura et al., 2017), level of detail (Ni, Bowman, & Chen, 2006), and negative symptoms and effects (Sharples et al., 2008). In architecture, an important limitation is that, although VR can be combined with auditory and tactile stimulation (Ellis, 1991), the richness of the experience is limited (Hughes, Van Dam, Foley, & Feiner, 1990). A simulation will always be a simulation (Moscoso, Matusiak, Svensson, & Orleanski, 2015), an abstraction of a complex reality (Wood & Fels, 2008) and, thus, VR cannot exactly reproduce physical environments (Rohrmann & Bishop, 2002). Therefore, studies that employ VR must be validated in physical environments (Higuera-Trujillo, López-Tarruella, & Llinares Millán, 2017; Rapoport, 1969; Shields, 2018). Despite these drawbacks, synthetic environments in general have been shown to be able to elicit behavioural responses similar to physical environments (Lombard, 1995) and VR has its uses in various fields (Duarte, Rebelo, & Wogalter, 2010) and, in particular, in architecture. It is a tool for architects and cognitive scientists interested in spatial perception and cognition.

3.2.3.3. Combined neuroscientific and virtual reality technologies

Neuroscience and VR can be combined (Hemeida & Mostafa, 2017). This combination allows researchers to develop virtual environments and record the neurophysiological and behavioural responses of experimental subjects (Bohil et al., 2011; Cho & Kim, 2017; Ergan et al., 2019; Merril, 1997; Radwan & Ergan, 2017; Riva, 2003). It has been suggested that this combination is more rigorous than research in physical settings using self-reports (Rizzo, Schultheis, Kerns, & Mateer, 2004). This is attractive for neuropsychological research (Tarr & Warren, 2002) and architecture (Jelić et al., 2016). Thus, combined VR/neuroscience techniques are increasingly being used to examine the psychological (Pasqualini et al., 2012) and neural bases of different aspects of the human-space relationship (Sanchez-Vives & Slater, 2005). The techniques are being used in visuomotor (Ghahramani & Wolpert, 1997) and spatial learning (Aguirre, Detre, Alsop, & D'Esposito, 1996), evaluations of cognitive rehabilitation (Pugnetti et al., 1995), assessments of social situations (Slater et al., 2006), training in simulated environments (Berka, Pojmani, Coyne, Cole, & Denise, 2010), quantification of sense of presence (Azevedo, Jorge, & Campos, 2014), and studies exploring the neurophysiological foundations of cognitive-emotional states, such as arousal (Bian et al., 2016; Chittaro, Sioni, Crescentini, & Fabbro, 2017; Kisker, Gruber, & Schöne, 2019; McCall, Hildebrandt, Bornemann, & Singer, 2015), stress (Biedermann et al., 2017; J. Lin, Cao, & Li, 2019; Tsai et al., 2018; Zimmer & Wu, 2019), and fear (Gromer, Reinke, Christner, & Pauli, 2019; Peperkorn, Alpers, & Mühlberger, 2014). The combined approach allows to evaluate the cognitive-emotional influence of architecture from a new perspective (Chiamulera et al., 2017).

3.2.4. The cognitive-emotional dimension of architecture measured through neuroaesthetics

Neuroscientific and virtual reality technologies have been extensively used in experiments in the related fields of art and aesthetics. They have provided a very valuable source of results and methodologies. The discipline derived from applying neuroscience to aesthetics has been called "neuroaesthetics". Neuroaesthetic research is an example of how technologies can contribute to the study of art (Chatterjee, 2013; Shimamura, 2013) and, since architecture shares lines of action with art and aesthetics, understanding the most illustrative innovations that have taken place in art and aesthetics represents an important new knowledge source for architecture (Biren, 2014).However, although a certain degree of extrapolation could be presumed, it should be noted that the current state of development of neuroarchitecture does not yet make it possible to determine to what extent extrapolation is possible. Below we discuss some landmarks that have been considered of special importance and affinity with architecture, considering contributions from different artistic contexts and, therefore, sensory modalities.

Psychology has developed various levels of analysis over the last century (Reimann, Zaichkowsky, Neuhaus, Bender, & Weber, 2010). Some of these analytical levels have focused on the "objective" and "subjective" aspects that influence the aesthetic experience (Höge, 1995).

Among the "objective" aspects related to the characteristics of objects are: (1) symmetry, (2) centre, (3) complexity, (4) order, (5) proportion, (6) colour, (7) context, and (8) processing fluency. Table 3.5 presents some effects and, where appropriate, related neurophysiological activity (RNA) and their Brede Database WOROI (a hierarchically structured directory of brain structures) codes. Many of these objective aspects have been approached intuitively, from different artistic disciplines, but applying a psychological approach provides new knowledge that can be of interest both to artists and researchers. For example, symmetry, which has been used frequently from early times in some architectural trends and styles, has been associated with faster cognitive processing of stimuli, but also with a certain aesthetic rigidity. Other less studied aspects are typicity (Halit, de Hann, & Johnston, 2000), semantic content, as opposed to formal qualities (Martindale & Moore, 1988), and style (Postrel, 2003). Many of these aspects are grouped in Ramachandran and Hirstein's (Ramachandran & Hirstein, 1999) theory of aesthetic experience. This conceptualises eight principles: peak shift effect, isolating single clues, perceptual grouping, contrast, perceptual problem solving, generic viewpoint, metaphor, and symmetry.

Table 3.5. Effects generated by the "objective" aspects frequently studied in psychology applied to art. The table incorporates some points about the neuronal activities involved (the nomenclature of the sources is followed, and WOROI codes are added).

Objective Aspect	Effect / Related Neurophysiological Activity (RNA)	Appreciation	WOROI
Symmetry	Symmetry and asymmetry can evoke emotional states (Frey, 1949).	Between both there is a wide spectrum of compositions (Gombrich, 1984).	
	General preference for symmetry (Frith & Nias, 1974).	In graphic patterns (Rentschler, Jüttner, Unzicker, & Landis, 1999).	
		In faces (Baudouin & Tiberghien, 2004; Rhodes, Proffitt, Grady, & Sumich, 1998).	
		Traditionally linked to beauty (Weyl, 2016).	
	Various artistic currents have used this (Ramachandran & Hirstein, 1999).	A certain tendency to break it to avoid rigidity (Goldberg, Funk, & Podell, 2012).	
	Detected rapidly in different circumstances (Julesz, 1971).	Including in art (Locher & Nodine, 1987).	
		May be due to a cognitive propensity to process (Arnheim, 1986).	
Symmetry	RNA: sustained posterior activity, spontaneously during its analysis (Höfel & Jacobsen, 2007).		21
Centre	The geometric centre of a visual work has special importance (Arnheim, 1982).	The "colorimetric barycenter" of a painting corresponds closely to its geometric centre (Firstov, Firstov, Voloshinov, & Locher, 2007).	
Colour	The colour of light has various influences at neurophysiological and behavioural levels (Jalil, Yunus, & Said, 2012).		
	RNA: Prefrontal cortex activity is related to coloured objects (Aminoff, Gronau, & Bar, 2007).		22
Complexity	Has great weight in aesthetic judgement (Biaggio & Supplee, 1983).		
	An aspect that lacks uniqueness (Popper, 1992), a part of other variables.	Has been combined with aspects such as symmetry (Arnheim, 1986).	
	Preference for moderate levels of complexity (Berlyne, 1970, 1974).	Its effects depend on the level of adaptation of the observer (Helson, 1964).	
	Preference in general for low fractal dimensions, between 1.3 and 1.5 (Spehar, Clifford, Newell, & Taylor, 2003); and for medium-high in architecture (Abboushi, Elzeyadi, Taylor, & Sereno, 2019).	Affects EDA recording (Taylor et al., 2005).	

Objective Aspect	Effect / Related Neurophysiological Activity (RNA)	Appreciation	WOROI
Order	Can improve the reading of a complex pattern and, therefore, its aesthetic evaluation; but a lack of complexity evokes monotony, and complexity without order evokes chaos (Appleton, 1975).	Some current architectural works are proof of this imbalance, this being one of the reasons for the increase in written explanations (Hildebrand, 1999).	
		Pattern recognition as a factor with a high impact on natural selection (Shermer, 2011).	
		Visual brain understood as a pattern-recognition device (Kandel, 2016).	
Proportion	Certain ratios, such as the golden section, generate greater preference (Höge, 1995).		
Context	Important when making general perceptual judgments (Bar, 2004; Fenske, Aminoff, Gronau, & Bar, 2006).	And when making aesthetic judgements in particular (Brieber, Nadal, Leder, & Rosenberg, 2014; Goldstein & Weber, 1997).	
		The representation of the context of an object in terms of its relationships to other objects or through a statistical summary of the scene (Oliva & Torralba, 2007).	
		A rapid affective precognitive assessment of the environment is undertaken, based on elements of the scene (Zajonc, 1980).	
	RNA: memory subsystems may be altered by context (Aminoff et al., 2007).		

Objective Aspect	Effect / Related Neurophysiological Activity (RNA)	Appreciation	WOROI
Context	RNA: the parahippocampal cortex participates in contextual associations (Aminoff et al., 2007).		65
	RNA: the retrosplenial cortex participates in contextual associations (Bar, 2007).		310
Processing fluency	Clear images are processed more easily (Ramachandran & Hirstein, 1999).	Contributes to making images more preferred (Leder, 2002; Reber, Winkielman, & Schwarz, 1998).	
		However, to distinguish certain basic scenes (such as indoor vs outdoor), very crude information might be sufficient (Oliva & Torralba, 2006).	
	Ambiguity is an inherent aspect of the process, relates to openness to multiple interpretations (Zeki, 2004).		
	RNA: The left fusiform gyrus seems to participate more in semantic processing, and the right fusiform gyrus in visual recognition (Simons, Koutstaal, Prince, Wagner, & Schacter, 2003).		133, 134

Among the "subjective" aspects, related to personal factors, are: (1) emotional state, (2) familiarity and novelty, (3) pre-classification, and (4) others of a social nature. Table 3.6 summarises some effects. These aspects complement the objective aspects, and play an important role (Kubovy, 2000). Subjective aspects have been addressed using different evaluation instruments, which highlights the variety of psychological tools available for application to art. For example, tools such as fMRI and EEG have been recently used to study the neurobehavioural effects of familiarity and novelty of stimuli, whose impacts on aesthetic judgement were already known at the psychometric level. In fact, neuroscience is advancing rapidly (Munar et al., 2012). Since the first event-related potentials in aesthetic judgment studies were published in 2000, a large number focused on aesthetics in painting have appeared (Zeki, 1999). Later, specific aspects of painting and other forms of artistic expression were addressed (Hagendoorn, 2004). A growing trend exists that is revealing the neurophysiological bases of the (previously discussed) objective and subjective aspects that influence the aesthetic experience.

Table 3.6. Effects generated by the "subjective" aspects frequently studied by psychology applied to art. The table incorporates some points about the neuronal activities involved (the nomenclature of the sources is followed, and WOROI codes are added).

Subjective Aspect	Neurobehavioural effect / Related Neurophysiological Activity (RNA)	Sub-effect / Appreciation	WOROI
Emotional state	Affects aesthetic judgement (Konecni, 1978).	Influences the way a work of art is processed (Forgas, 1995).	
		Tendency to memorise and associate information consistent with the emotional state of the subject (Bower, 1981).	
	Affects judgement of distance		
Familiarity – Novelty	Affects aesthetic judgement (Berlyne, 1970, 1971; Kirk, Skov, Christensen, & Nygaard, 2009; Zajonc, 1968).	Objects are processed more efficiently in a familiar context (Boyce, Pollatsek, & Rayner, 1989; Davenport & Potter, 2004).	
		For a work to be attractive it must be located in a specific range of the "novelty/familiarity" ratio (Goldberg et al., 2012).	
	RNA: the frontal lobe and the right hemisphere participate in novelty processing (Goldberg et al., 2012)		18, 707
	RNA: blood-oxygen-dependent level is reduced by repeating an image (Biederman & Vessel, 2006).		

Subjective Aspect	Neurobehavioural effect / Related Neurophysiological Activity (RNA)	Sub-effect / Appreciation	WOROI
Familiarity – Novelty	RNA: the gamma band exhibits greater activity in the inferior-temporal, superior-parietal and frontal brain areas when viewing familiar than non-familiar objects (Supp, Schlögl, Trujillo-Barreto, Müller, & Gruber, 2007)		16, 168, 18
	RNA: the gamma band exhibits a stronger increase after 250ms of identification of familiar objects (Martinovic, Gruber, & Müller, 2007).	Related to increased activity in the gamma band in the occipital (Keil, Müller, Ray, Gruber, & Elbert, 1999) and frontal areas, when observing ambiguous objects (Başar-Eroglu, Strüber, Kruse, Başar, & Stadler, 1996).	26, 18
Pre-classification	Previous considerations affect aesthetic judgment.	Knowing that a work of art is a forgery alters both familiarity and aesthetic judgements (Leder, 2001).	
	RNA: neural activity can be modulated by external influences, as with the semantic labelling of scents (de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005).		
Social: Social Status	Demonstrations of dominance or wealth influence aesthetic judgment (Ritterfeld, 2002).	Related to activation of the reward-related brain areas (Erk, Spitzer, Wunderlich, Galley, & Walter, 2002).	
	RNA: reward circuitry most activated by objects associated with wealth or social dominance (Schaefer & Rotte, 2007).		
	RNA: Knowing the economic value of a product increases preference and activation of the medial OFC (Plassmann, O'Doherty, Shiv, & Rangel, 2008).		698

Subjective Aspect	Neurobehavioural effect / Related Neurophysiological Activity (RNA)	Sub-effect / Appreciation	WOROI
Social: Culture	Modulates visual perceptual processing (Gutchess, Welsh, Boduroĝlu, & Park, 2006).	Affects even basic visual aspects, such as colour (Chebat & Morrin, 2007).	
	Related to artistic sensitivity (Eysenck & Hawker, 1994).	Can be developed with expertise, something for which humans are perhaps conditioned, given that a self-rewarding experience is elicited when a work is recognised (Gordon & Holyoak, 1983).	
		Significant in aesthetic judgement (Barron & Welsh, 1952; Hekkert & van Wieringen, 1996b).	
		Behavioural differences in terms of how experts and non-experts experience art (Hekkert & van Wieringen, 1996a).	
		Related to style-based processing (Winston & Cupchik, 1992).	
		Architectural eye tracking-based studies (Iñarra, Vidal, Llinares, & Guixeres, 2015).	
	RNA: expertise generates different event-related potentials in aesthetic judgment (Müller, Höfel, Brattico, & Jacobsen, 2009).		
	RNA: expertise generates different eye-movement patterns and visual memory (Vogt & Magnussen, 2007).		
	RNA: expertise generates changes in memory- and perception-related structures (Bangert et al., 2006).		
	RNA: expertise helps to execute creative processes faster (considering that these involve a decrease in average arousal measured through EDA and EMG).		

Distinctions are normally made between the neurophysiological foundations of attention, judgement and emotion (Cela-Conde et al., 2013). Table 3.7 summarises some effects. Taking attention, it has been found that visual processing occurs both in parallel and hierarchically (Farah, 2000), as more complex issues are gradually solved (Marr, 1982). In terms of artistic judgement, there are two stages, a general impression of works at around 300ms, and a deeper aesthetic evaluation at around 600ms (Jacobsen & Höfel, 2003). Regarding emotion, aesthetics is a complex experience that involves different affective-emotional processes that activate reward-related brain regions (Blood & Zatorre, 2001); reward is understood as the positive value attributed to something (Wise & Rompre, 1989). Hemispheric specialisation has also received attention (Schwartz, Davidson, & Maer, 1975). Some studies have seemed to suggest that there are asymmetric functions in the brain hemispheres, and while they might be activated by the same stimuli, they react in different ways (Kosslyn, 1987). Thus, while two parts of the brain might be activated by the same stimuli, only one would be the final controller. However, aesthetic experience involves different aspects (Kirk, Skov, Hulme, Christensen, & Zeki, 2009), processed through the same systems used in other areas (Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011). In this sense, mirror neurons are interesting. Mirror neurons are activated both when carrying out an action and when observing it: the observers' neurons "mirror" (hence the name) the behaviour of the individual carrying out an action, as if the observers themselves were performing it. It has been suggested that the behaviour of mirror neurons is important to social life-linked cognitive capacities, such as empathy (Decety & Jackson, 2004), but also to the empathic understanding of art (Freedberg & Gallese, 2007); and therefore also in the specific context of architecture (Mallgrave, 2013).

Table 3.7. Neurophysiological foundations of the aesthetic experience (the nomenclature of the sources is followed, and WOROI codes are added).

Aspect		Related Neurophysiological Activity	WOROI
Attention	Stimulus location	Frontal eye field (Serences & Yantis, 2006).	34
		Cingulate cortex (Lane et al., 1998).	4
	Attention given to external stimuli	Rostral prefrontal cortex (Ernst, Weidner, Ehlis, & Fallgatter, 2012). Also plays a role in emotion regulation (Campbell-Sills et al., 2011) and memory (Volle, Gilbert, Benoit, & Burgess, 2010).	46
	Observation	Dorsolateral prefrontal cortex (Kirino, Belger, Goldman-Rakic, & McCarthy, 2000), when stimuli deviate from expectations.	89
		Inferior temporal area at around 170ms (Munar et al., 2011), in visual art.	16
		Insula (Di Dio, Macaluso, & Rizzolatti, 2007).	67

Aspect	Related Neurophysiological Activity	WOROI
Judgement	General impression (at around 300ms): greater negativity in the ERPs of stimuli judged as not being beautiful ((Höfel & Jacobsen, 2007). Generated by, among others, the right lateral orbitofrontal cortex (Munar et al., 2012) and the medial rostral prefrontal cortex (Ishizu & Zeki, 2011; Vartanian & Goel, 2004).	286, 46
	Deep evaluation (at around 600ms): hemispheric lateralisation to the right hand side of the brain, especially positive when looking at something beautiful (Höfel & Jacobsen, 2007).	
	Prefrontal area (Cela-Conde et al., 2004).	22
	Left prefrontal dorsolateral cortex, between 400ms and 1000ms (Cela-Conde et al., 2004).	90
	Orbitofrontal cortex (Francis et al., 1999) and its lateral subregion (Small et al., 2003; Wallis, 2007); also for ugly stimuli (Kirk, 2008). Related to reward evaluation (Kringelbach & Rolls, 2004) and the taking of morality-related decisions (Tsukiura & Cabeza, 2011).	685, 286
	Connection between the orbitofrontal cortex, anterior insula, rostral cingulate, and ventral basal ganglia (Brown et al., 2011); suggestive of exteroceptive and interoceptive information comparisons.	685, 97, 363, 35
	Medial orbitofrontal cortex (Zeki & Stutters, 2012). Activated together with the perceptual area specialised in the specific stimulus mode (Ishizu & Zeki, 2011).	685
	Anterior medial prefrontal cortex (Vessel, Starr, & Rubin, 2012).	55
	Motor cortex (Kawabata H. & Zeki, 2004). Also while observing sculptures (Di Dio et al., 2007).	214
	Left parietal cortex (Kawabata H. & Zeki, 2004) and its subdivision, the precuneus (Teasdale et al., 1999). Concordant with the highest amplitude found in the P3 electrode (de Tommaso et al., 2008).	83, 171
	Left cingulate sulcus, bilateral occipital poles, and fusiform gyri, with greater activation when looking at preferred pictures (Taylor, Phan, Decker, & Liberzon, 2003).	4, 26, 62

Aspect	Related Neurophysiological Activity	WOROI
Judgement	Occipito-temporal cortex (Kim, Adolphs, O'Doherty, & Shimojo, 2007).	178
	Right primary visual cortex (Paradiso et al., 1999).	311
	Anterior cingulate cortex (Kawabata H. & Zeki, 2004).	8
	Right anterior insula (Brown et al., 2011).	454
	Right parahippocampal cortex (Yue, Vessel, & Biederman, 2007).	132
	Caudate nucleus (Ishizu & Zeki, 2011), specifically the right-hand side (Vartanian & Goel, 2004).	39
	Putamen (Ishizu & Zeki, 2011).	38
	Putamen and claustrum (Ishizu & Zeki, 2013).	38,181
	Globus pallidus (Ishizu & Zeki, 2013).	113
	Amygdala (Di Dio & Gallese, 2009; Ishizu & Zeki, 2013).	36
	Connection between the frontal cortex, the precuneus, and the posterior cingulate cortex (Jacobsen, Schubotz, Höfel, & Cramon, 2006).	18, 171, 5
	Default mode network, showing increased activation while viewing highly-pleasing images (Vessel et al., 2012).	
Emotion	Orbito-frontal cortex, and its medial subdivision, in different sensorial modes. Taste: (Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001); Smell: (Gottfried, Deichmann, Winston, & Dolan, 2002); somatosensory: (Aminoff et al., 2007); vision: (Kawabata H. & Zeki, 2004).	685, 285
	Medial temporal lobe (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000).	218
	Fusiform gyri when looking at smiling faces (Iidaka et al., 2002).	62
	Striatum (Yue et al., 2007).	37
	Nucleus accumbens (Salimpoor et al., 2008).	245
	Hippocampus (Koelsch, Fritz, Müller, & Friederici, 2006).	40
	Amygdala (Koelsch, Fritz, & Schlaug, 2008).	36

Neural activities have been identified in relation to aspects studied in psychology. Tables 6 and 7 display some of these. That the structures involved are both subcortical and cortical -commonly associated with emotion and reason- is the basis of romantic hypotheses about the complexity of art, and the difficulty of producing beauty, in comparison to perceiving it. Given the close coordination between these structures (Miller & Clark, 2018), it would make sense to accept that the interaction between the structures is both bottom-up and top-down (Cupchik, Vartanian, Crawley, & Mikulis, 2009).

Different models establish links between studies. On the one hand, the Leder psychological model (Leder, Belke, Oeberst, & Augustin, 2004) emphasised the interdependence of emotion and aesthetic judgment (they occur simultaneously: the first is the source of aesthetic preference, the second the output of affective-emotional states) and established five phases of aesthetic experience (perception, explicit classification, implicit classification, cognitive mastering, and evaluation). On the other, the Chatterjee neuroscientific model (Chatterjee, 2004) proposes that, in addition to affective-emotional output, there is a decision-making process. The model establishes five phases (processing of simple components, attention to prominent properties, attention modulation, feed-back/feed-forward processes uniting the attentional and attributional circuits, and intervention of the emotional systems). The fundamentals of the Chatterjee's model have recently been contextualised in architecture (Coburn, Vartanian, & Chatterjee, 2017). Both frameworks represent the aesthetic experience, and have been useful for interpreting later results (Nadal, Munar, Capó, Rosselló, & Cela-Conde, 2008). However, further research is needed.

3.2.5. Neuroscience in architecture

Neuroscience is being incorporated into the study of the cognitive-emotional dimension of architecture (Linaraki & Voradaki, 2012). Seen in retrospect, certain gestalt psychology-influenced developments link the use of neuroscience in architecture (Jelić, 2015). Von Hayek's work (1952) and Arnheim's research (2004) into the psychology of art and perception of images are examples. Beyond gestalt, and strictly outside art, Hebb (1949) made a contribution to the application of neuroscience to behaviour by developing a theory of how complex psychological phenomena can be produced by brain activity. Paired with his ideas, Neutra made one of the first more explicit contemporary formulations of the incorporation of neuroscientific knowledge into architecture (Neutra, 1954). He explained that architecture should satisfy the neurological needs of its users, by incorporating the research available into the development of architectural designs. Also inspirational is the holistic understanding of human life that Moholy-Nagy expected from architects (Moholy-Nagy, 1929). The point at which this knowledge began to be accessible to architects, according to some authors (Robinson & Pallasmaa, 2015), was with the publication of "The Embodied Mind" (Varela et al., 2016). In this work the authors coined the term "neurophenomenology", and tried to reconcile the scientific approach with experience (Vijayan & Embi, 2019). In this sense, Einfühlung has also acquired a neuroscientific substrate in recent years: Freedberg & Gallese (2007) proposed that mirror neurons are responsible for what certain phenomenology authors called "resonance". In this way, neuroscience applications, compared to base approaches, offer substantial benefits (Ulrich, 1981).

Two lines stand out in the exploration of architecture's bases: the design process, and the experience of architecture (Arbib, 2015). The first line has been widely developed in art in general, and has made progress in the architectural field, for example, in proposals on how to incorporate the knowledge derived from neuroscience's application to architecture into the design process (Banasiak, 2012; Edelstein & Sax, 2014; Manganelli et al., 2012); and in studies into brain development generated by acquired expertise (Kirk, Skov, Christensen, et al., 2009; Wiesmann & Ishai, 2011). These studies share common ground with neuroaesthetic research. Frequently examined aspects of the second line are orientation, light, and acoustics. Orientation is part of the daily activity of most people (Hoffman, 2012). Studies of diverse natures have tried to explain the principles involved in wayfinding (Golledge, 1999; Hillier & Hanson, 1984; Peponis & Wineman, 2002), with VR being seen to be an effective tool (Edelstein, Gramann, et al., 2008). These studies have direct relevance when it comes to improving navigation strategies. There is a long tradition of using light for aesthetic purposes. Since the discovery of the eye's photoreceptive ganglion cells, and their influence on circadian rhythms (Brainard et al., 2001; Thapan, Arendt, & Skene, 2001), light-centred studies have been complemented by health-focused research (Ellis et al., 2013). The application of the recommendations based on the results of light-based research could improve the experience of users, especially those with time/light challenges (e.g. night shift workers) (Edelstein, 2009). Regarding acoustics, there is a relationship between noise and consequences for humans at different levels (Ising & Raun, 2000). For example, studies have been undertaken into stress recovery during exposure to sounds of different quality (Alvarsson, Wiens, & Nilsson, 2010). Leaving aside artistic arguments, the treatment of space acoustics is of considerable importance. In addition to these aspects (orientation etc.), studies that identify the mechanisms of exposure to restorative environments should be highlighted (Martínez-Soto, Gonzales-Santos, Pasaye, & Barrios, 2013), as should studies into the quantification, based on neurophysiological measures, of the effects of restorative environments in interior (Choi, Kim, & Chun, 2015) and exterior spaces (Martínez Soto, Nanni, Gonzales-Santos, Pasaye, & Barrios, 2014; Tilley, Neale, Patuano, & Cinderby, 2017), the capture of the emotional impact of museum experiences (Alvarez, 2014; Du et al., 2016; Kirchberg & Tröndle, 2015; Tschacher et al., 2012), the modification of recommended house design variables (Lacuesta, Garcia, García-Magariño, & Lloret, 2017), and works with mixed design aspects (Tsunetsugu, Miyazaki, & Sato, 2005). The results of some studies appear in Table 3.8. Beyond the relative prominence of wayfinding studies, in this table it can be seen that some variables attract more attention (as do environmental psychology and EBD). The variable contours and ornament, a basic architectural design aspect, stands out. These advances show the usefulness of the neuroarchitectural approach to the cognitive-emotional dimension of architecture (Chow, 2015; Edelstein, 2006a; Kayan, 2011). However, although neuroscientific research is extensive and rigorous, its application to architecture is an emerging discipline (Arbib, 2014; Dance, 2017). Thus, there are, as yet, few practical works exclusively focused on improving architectural design. The efforts are dispersed, and a common framework has yet to be established.

Table 3.8. Neurophysiological foundations of the cognitive-emotional dimension of architecture, and the neurobehavioural effects generated by architectural design variables studied in the application of neuroscience to architecture.

Aspect / Variable	Neurobehavioural effect/ Related Neurophysiological Activity	WOROI
Wayfinding	Posterior parietal, premotor, and frontal areas, greater activation when the subject uses an egocentric frame of reference (Gramann, Müller, Schönebeck, & Debus, 2006).	21, 217, 18
	Occipito and temporal area, greater activation when the subject uses an allocentric frame of reference (Gramann et al., 2006).	26, 15
	Parietal zone with desynchronised alpha band, in environments where orientation is difficult (Zhang et al., 2011).	290
	Occipital area, processes visual features important for landmark recognition (Marchette, Vass, Ryan, & Epstein, 2015).	26
	Medial temporal area, related to allocentric representations (Burgess, Maguire, Spiers, & O'Keefe, 2001).	136
	Right lingual sulcus, participates in perception of buildings (Aguirre, Zarahn, & D'esposito, 1998).	167
	Posterior cingulate cortex, and occipital lobe, involved in navigation and perception from different perspectives (Banaei, Hatami, Yazdanfar, & Gramann, 2017).	5, 26
	Anterior midcingulate cortex, greater activation in closed spaces; possibly generating avoidance decisions (Vartanian et al., 2015).	8
	Entorhinal cortex, relating memory and navigation data to create a cognitive map of events (McNaughton, Battaglia, Jensen, Moser, & Moser, 2006).	66
	Retrosplenial complex retrieves landmark-related spatial and conceptual information (Marchette et al., 2015).	310
	Hippocampus, right posterior parietal, and posterodorsal medial parietal cortex, related to the retrieval of spatial context (Burgess et al., 2001).	40, 290, 21
	Right hippocampus, participates in the remembering of locations (O'Keefe & Nadel, 1978).	108
	Left hippocampus, participates in the remembering of autobiographical events (Zola-Morgan, Squire, & Amaral, 1986).	107
	Hippocampus, with higher activation in the theta band, hypothetically related to sensorimotor integration during navigation (Ekstrom et al., 2005).	40

Aspect / Variable	Neurobehavioural effect/ Related Neurophysiological Activity	WOROI
Wayfinding	Parahippocampus codes landmark identity (Marchette et al., 2015).	65
	Parahippocampus, participates in the spatial processing of scenes (Burgess, Maguire, & O'Keefe, 2002; Epstein, Harris, Stanley, & Kanwisher, 1999).	65
	Parahippocampus; responds, in general, to rectilinear features (Nasr, Echavarria, & Tootell, 2014).	65
	Alpha band, with increased activation in occipital electrodes, associated with familiar streetscape images (Kacha, Matsumoto, & Mansouri, 2015).	26
	Beta band, with increased activation in frontal electrodes, positively correlated with RMS (root-mean-square) statistics and fractal dimensions (Kacha et al., 2015).	18
	Alpha and beta bands, indicating that the first three minutes of walking has the greatest cognitive effects on users (Banaei, Yazdanfar, Nooreddin, & Yoonessi, 2015).	
	Theta band, with increased activation, associated with increased navigation performance in women and decreased navigation performance in men (Kober & Neuper, 2011).	
	Theta/alpha ratio, related to higher cognition and memory (Erkan, 2018).	
Stress	Middle frontal gyrus, middle and inferior temporal gyrus, insula, inferior parietal lobe, and cuneus with higher activation in highly restorative potential environments (Martínez-Soto et al., 2013).	148, 126, 67, 183, 3
	Superior frontal gyrus, precuneus, parahippocampal gyrus, and posterior cingulate with higher activation in low restorative potential environments (Martínez-Soto et al., 2013).	70, 171, 65, 5
	Alpha band with higher activation in the frontal lobe in non-stressful environments (Choi et al., 2015).	18
	High-beta band with higher activation in the temporal lobe in stressful environments (Choi et al., 2015).	15
	A combination of multisensory design variables produces a synergistic effect which reduces stress; measured through EDA (phasic), HRV (LFHF), and EEG (AAPEn) (Higuera-Trujillo et al., 2020).	

Aspect / Variable	Neurobehavioural effect/ Related Neurophysiological Activity	WOROI
Illumination	White light modulates mood and sleep rhythms (Ancoli-Israel et al., 2003).	
	Spaces illuminated above 7500K increase blood pressure (Kobayashi & Sato, 1992).	
	Arousal differences demonstrated (measured using EEG) in spaces illuminated at 5000K and 3000K (Noguchi & Sakaguchi, 1999).	
	Blue light accelerates post-stress relaxation (Minguillon, Lopez-Gordo, Renedo-Criado, Sanchez-Carrion, & Pelayo, 2017).	
	Direct/indirect lighting makes subjects feel cooler and more pleasant, compared to direct lighting. It also generates more activity in electrodes F4, F8, T4, and TP7. Under these circumstances, the theta band of the F8 electrode correlated with a "cool" self-assessment (Shin et al., 2015).	91, 296, 130, 123
	Difference between cold and neutral colour temperature, at the level of alertness, fatigue, cognitive functioning, HRV (HR) and EDA (Soto Magan, Webler, & Andersen, 2018).	
Colour	Red coloured spaces increase arousal measured through EEG metrics (Küller, Mikellides, & Janssens, 2009).	
Contours and ornaments	Anterior cingulate cortex, greater activation when looking at curvilinear spaces (Vartanian et al., 2013).	8
	Anterior cingulate cortex with theta band, related to certain spatial characteristics (Banaei, Hatami, et al., 2017)	8
	Frontal lobes with event-related potentials of higher positive amplitude, between 300 and 600ms, when viewing architectural ornaments (Oppenheim et al., 2009). Susceptible to cultural modulation (Mecklinger, Kriukova, Mühlmann, & Grunwald, 2014).	18
	Curved geometric spaces are preferred over angled geometric spaces (Vartanian et al., 2013).	
	Curved geometric spaces are preferred by non-design expert subjects; and sharp-angled spaces by expert subjects (Shemesh et al., 2016).	
	Angled geometry is not avoided, but curved geometric spaces prompt approach (rather than avoidance) behaviours (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016).	

Aspect / Variable	Neurobehavioural effect/ Related Neurophysiological Activity	WOROI
Contours and ornaments	Amygdala with greater activation when viewing sharp than curved contours, and images of landscapes and healthcare objects. However, when viewing images of hospital interiors and exteriors, there is greater activation with curved contours. it is hypothesised that, in stress-associated environments, curved contours may not be desirable (Pati, O'Boyle, Hou, Nanda, & Ghamari, 2016).	36
	Open-office arrangements generate more physical activity, and less stress, measured through HRV (SDNN) (Lindberg, 2018).	
	Thigmotaxis plays a role in spatial learning, depending on the phase (Kallai et al., 2007). Human predisposition for walls: people are thigmotactic (Sussman & Hollander, 2014).	
Windows	The existence of openings can reduce stress, measured by electrocardiogram (HR, and HRV-HF, and T-wave amplitude), and cortisol. However, this depends on stressor type (Fich et al., 2018).	
	The geometry of façades, and the lighting that passes through them into interiors, affects physiological (at HRV level) and psychological responses in different ways. Among others, there is deceleration of the heart rate with irregular designs, in comparison to blinds, perhaps because they attract greater attention (Chamilothori et al., 2018, 2019).	
Aesthetic judgement	Left frontal areas with more theta band activity when viewing pleasant interior spaces (Vecchiato, Jelic, et al., 2015).	81
	Fusiform face area, involved in fine-grained neural encoding of architectural scenes (Choo, Nasar, Nikrahei, & Walther, 2017).	343
	Theta band increased across the frontal area, in familiar and comfortable environments (Vecchiato, Tieri, et al., 2015).	18
	Alpha band increased in left-central parietal and frontal areas, in pleasant environments (Vecchiato, Tieri, et al., 2015).	83, 18
	Mu band desynchronised in left motor areas, in pleasant and comfortable environments (Vecchiato, Tieri, et al., 2015).	350

Aspect / Variable	Neurobehavioural effect/ Related Neurophysiological Activity	WOROI
Nature	Views of nature have positive effects on emotional and physiological states (Ulrich, 1986).	
	Natural vistas (in videos) produce significantly higher HR than urban vistas (Laumann, Gärling, & Stormark, 2003).	
	The absence of vegetation generate a more oppressive environment, which affects the judgment of distance and generates greater arousal measured through EDA (Mazumder & Ellard, 2018).	
	Similar brain patterns between positive images and open sky multisensory simulations, measured through fMRI. The latter also generate activity related to spatial cognition and space expansion (Navarrete, 2018).	

4. Discussion

Based on the scoping review of neuroarchitecture and its precursor approaches, four aspects of the application of neuroscience to architecture were identified: (1) limitations of the approaches; (2) the problems in addressing the cognitive-emotional dimension of architecture; (3) ways to solve the problems; and (4) the limitations of this work.

4.1. Limitations of the approaches to the study of cognitive-emotional dimension of architecture

The study of the cognitive-emotional dimension of architecture is complex. New approaches are helping to overcome the limitations of the base approaches and to identify data that can support the validity of design proposals. However, neither approach is without its limitations.

The base approaches to the cognitive-emotional dimension of architecture are generally limited in relation to the environmental stimuli and the evaluations systems used. The new approaches, to an extent, try to overcome these limitations by incorporating VR and neuroscience; their application to aesthetics and art provide a basis for their application to architecture. However, the fact that art and architecture are related fields does not make them equivalent; thus, the extrapolation of other knowledge bases to architecture must be undertaken with caution. These aspects are discussed below at ontological, epistemological and methodological levels.

At an ontological level, the limitations derive from the perceptual breadth of the experiences. Two deficiencies stand out: (1) the modality of the stimuli used; and (2) the aspects studied. The first limitation involves unimodality. Previous studies have generally focused on the visual domain (Skov, 2009). Although most of the information we process is in the visual domain (Bourdieu, 1989; Bruce, Green, & Georgeson, 2003), limiting the exposure to just unimodal stimuli in architecture reduces the richness of the experience (Ebrahem, 2018; O'Neill, 2001). The second limitation fundamentally involves beauty and pleasure. On the one hand, although beauty plays a central role in people's concept of aesthetics, art and, therefore, architecture (Jacobsen, Buchta, Kohler, & Schroger, 2004), non-beautiful works can be art (Richter & Britt, 1997). On the other, although pleasure may be derived from the aesthetic or artistic experience (Clay, 1908), pleasurable feelings may be generated for reasons outside the work of art or architecture. Thus, beauty and pleasure are not enough (Brown & Dissanayake, 2009).

At the epistemological level, the limitations derive from the difficulty of explaining these experiences in exclusively physiological terms. Two stand out: (1) the neurology-experience relationship; and (2) the various influential aspects. The first limitation generates the risk of drawing invalid inferences, since a brain area can be related to several processes (Poldrack, 2006). Emotions are especially complex in this regard (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). The second limitation relates to the number of aspects that influence artistic and aesthetic experiences (Cela-Conde et al., 2011). These experiences may seem simple because they are simple to recognize, but not at the neuro-psychological level.

At a methodological level, the limitations derive from the wide variety of stimuli and the many ways in which works can be displayed. Two stand out: (1) procedural conflicts; and (2) technical restrictions. The first limitation involves several questions. On the one hand, ceteris paribus logic sacrifices the complexity of the stimuli. In addition, the rigidity of neuroimaging protocols and the laboratory context can alter results. On the other, the multiple cognitive-emotional processes involved do not occur simultaneously (Winkielman & Cacioppo, 2001), which may misalign the causal assignment of the recordings. The second limitation relates to the restrictions associated with neurophysiological recording technologies, for example, the immobility of fMRI. Although these limitations can now be considerably addressed using other devices, such as wearable EEG caps (Lindquist, Williams, & Oloyede, 2014) and recordings can be made outside the laboratory (Babiloni et al., 2014; Siddharth Patel, Jung, & Sejnowski, 2018; M. Smith, Nanda, Macagno, & Greving, 2018), they must be taken into account. The limitations all contribute to the lack of a commonly-accepted methodology. In a certain way, this lack also obstructs the understanding between different research groups and the comparability of results. While sometimes studies might provide divergent results, it may be because they are reflecting different components of the experience (Locher, Krupinski, Mello-Thoms, & Nodine, 2007). What leads to the point that the results are also difficult to extrapolate into design guidelines for practical application in architecture.

4.2. Problems in addressing the cognitive-emotional dimension of architecture

In addition to the limitations discussed above (applicable to the entire domain of art and aesthetics), there are more specific architecture-based limitations. Mainly two: (1) it is not possible to liken architecture to the artistic-aesthetic; and (2) the experience is not one-off. The first limitation arises from the depth of the architectural function. Architecture tries to meet broad human needs (Andreasen, 1985). Although architecture is one of the "Fine Arts" (Batteux, 1746), the artistic-aesthetic experience is only one of the components of the cognitive-emotional dimension of architecture. The second limitation is that architecture is an experiential continuum (Holl, 2011). The transition from one space to another can condition the experience (Djebbara, 2018), the "architectural narrative" being significant (Sussman & Hollander, 2014). In addition, peripheral vision is of special importance (Srikantharajah, Ellard, & Condia, 2018); in fact, architecture could be experienced in two ways: intellectually, through focal processing, and in terms of atmosphere, through ambient processing (Rooney, Condia, & Loschky, 2017). Furthermore, architecture engages all sensory modalities (Mehta, 2014; Papale et al., 2016), so the visual is insufficient to describe it (Dzebic et al., 2013). This is very important in terms of the study of sensory interaction (Marks, 1978). Both limitations impede the fragmentation of the cognitive-emotional dimension of architecture, which encourages the tendency to case studies (Jones & Canniffe, 2007). In summary, the application of neuroscience to other fields must be cautiously extrapolated to architecture.

The debate on the universality of art should not be forgotten (Dutton, 2009; Trehub, 2000). Fundamentally, a perspective based on objective principles might be considered (Child, 1978), but differences between individuals makes the artistic experience widely subjective (Reber, Schwarz, & Winkielman, 2004), a circumstance echoed in architecture (Zumthor, 2014). To deploy ideas about the universality of art requires retrospective exposition. To begin with, art has developed in parallel with human evolution (Appenzeller, 1998). Indeed, it is an exclusively human capacity; different from the structures that some animals produce based on their genetic programming (Robinson & Pallasmaa, 2015). This is not a reference to the denaturation of art (Skov & Nadal, 2018), but to its human focus. The key point is that the brain adapts to the environment (Rakic, 2002), a process known as "neuroplasticity" (Livingston, 1966). Thus, our artistic (and, therefore, architectural) experience is conditioned by biological and environmental factors (Kozbelt, 2017), the latter having a major impact (Whitfield, 1984). Also, human brains may change through pathologies (e.g. Alzheimer's disease). Achieving universal art or architecture may not be possible. In fact, there is less agreement when it comes to judging artifacts than natural elements (Vessel, Maurer, Denker, & Starr, 2018). However, all humans have innately similar brains (Cupchik, Winston, & Herz, 1992; Swaab, 2014), which allows bridges to be built between individuals, societies, and times (Ackerman, 1992). Therefore, some common architectural design guidelines may be developed.

4.3. Beyond the current state. The challenges facing neuroarchitecture and its constituent disciplines

Hitherto, there has been no general study of the foundations underlying the cognitive-emotional dimension of architecture. In this sense, neuroarchitecture has potential. The new discipline makes a contribution to an architecture that supports the cognitive-emotional dimension (Pallasmaa, Mallgrave, & Arbib, 2013), and does not fall into the reductionism of exclusively aspiring to provide relaxation (Ruggles, 2017). This might embrace the contemporary emphasis on sustainability and the social dimension (Eberhard, 2012). The examples are as varied as the spaces: hospitals that contribute to healing (Sternberg, 2009), classrooms that support cognitive processes (Turk, Amr, & Al Rawi, 2018), work environments that encourage collaboration (Goldstein, 2006), museums perceptually adapted to the works that they house (Babiloni et al., 2014), restaurants where multisensory integration enhances the gastronomic experience (Auvray & Spence, 2008) and, among others, urban planning activities (Hollander, J., & Foster, 2016; Mavros, Austwick, & Smith, 2016; Portugali, 2004; Taylor-Hochberg, 2018), where one of the challenges lies in the diversity of groups. Indeed, designing for specific groups -including those with specific pathologies, such as dementia (Barrett, Sharma, & Zeisel, 2019; Zeisel, 2013; Zuanon & de Faria, 2018)- involves a frontal confrontation with design for the masses. The success of the different applications of neuroarchitecture will, in part, depend on the ability of its constituent disciplines to overcome its inherent challenges.

User experience is the main issue in VR. Increasing the capacity of VR set-ups to generate the illusion of being in a place (characterised as "place illusion"), and the credibility of the scenarios, to meet the viewer's expectations (characterised as "plausibility illusion"), is crucial. Although there is limited understanding of what affects sense of presence, there is consensus on two factors, exteroception and interoception. Exteroception factors, which are directly related to the experimental set-up (such as interactivity), increase sense of presence particularly in virtual environments not designed to induce specific emotions (Slater, Usoh, & Steed, 1994). Interoception factors, defined by the content displayed, increase presence if the user feels emotionally affected (Riches, Elghany, Garety, Rus-Calafell, & Valmaggia, 2019). For example, previous studies have found a strong correlation between arousal and presence (Diemer et al., 2015). This suggests that, in neuroarchitecture, both factors may be critical. There is a robust interdisciplinary community (Cipresso, Giglioli, Raya, & Riva, 2018) that is certainly helpful in meeting this challenge. Furthermore, neuroarchitecture and VR share a synergistic relationship in which the former can help us understand and improve virtual spaces, with which we interact more and more.

The analysis of neurophysiological data is challenging (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009). Affective computing, an interdisciplinary field based on psychology, computer science, and biomedical engineering (Picard, 2000), will probably play an important role. Several studies have focused on identifying the cognitive-emotional state of subjects by using machine-learning algorithms, achieving high levels of accuracy (Valenza, Lanata, & Scilingo, 2012; Zangeneh Soroush, Maghooli, Setarehdan, & Motie Nasrabadi, 2018). Many neuroimaging techniques have been used (Calvo & D'Mello, 2018). Affective computing can be transversally applied to many human behaviour topics. Although one of the first applications of affective computing was to neuroeconomics research, due to the important relationship that has been found between emotions and decision-making (Camerer, Loewenstein, & Prelec, 2005), there are revealing and important examples of its application to architecture (Fernández-Caballero et al., 2016). In fact, very recent applications in virtual architectural spaces have produced encouraging results (Marín-Morales et al., 2019, 2018; Marín-Morales, Llinares, Guixeres, & Alcañiz, 2020). For neuroarchitecture, the definition of neurophysiological indices in relation to the cognitive-emotional dimension of architecture would contribute to the development of an actual architectural design tool. These would allow the effect of the architecture on users to be measured in an easy-to-interpret way (e.g. stress through neurophysiological measures expressed in well-defined ranges). The fact that these indices have not yet been fully developed and made available for academic and professional use is one of the reasons that may be holding back the growth of neuroarchitecture. Developed in real time, these could even contribute to adapting spaces to emotional states (Arbib, 2012) (for example, automatically modify the lighting of the environment in order to respond to a stressful situation of its user). In this matter, the combination with virtual reality could potentially present yet another facet of the synergy between neuroimaging and virtual reality techniques. For example, by means of augmented reality displayed on HMDs the user could be stimulated to reduce their stress, without physically modify variables of the environment (which could affect other users who do not meet the same needs). Thus, neuroarchitecture would not only help to answer questions about the cognitive-emotional dimension of architecture, but also to develop a technological layer that supports our cognitive-emotional processes (Arbib, Ngoon, & Janes, 2018).

However, humans are not just neurological entities. Thus, it is not surprising that the cognitive-emotional dimension of architecture has been approached from such different directions. The polyhedral nature of the cognitive-emotional dimension of architecture means that a solution can hardly be derived from one source. Although neuroscience applied to architecture helps to answer questions about the cognitive-emotional dimension of architecture, it does not hold all the answers. Moreover, architecture has traditionally been based on designerly ways of knowing: the architect intuitively explores and exploits some of its perceptual foundations. What offers an economy of means that, sometimes, is ahead of science (Lehrerm, 2010). Thus, if the ultimate goal is to improve architecture, attention must be paid to both the bases and execution; to do this it will be necessary to take into account how architects work. "Scientists and artists need to identify common ground" (Pepperell, 2018). Only in this way will it be possible to develop the broad and deep knowledge needed to generate a true design tool.

4.4. Limitations of the work

The present study has some limitations. Fundamentally: (1) the work may be over-exhaustive; and (2) possible significant references were not discovered. Exhaustiveness is due to the multiple disciplines involved. Although some overlap exists, the integration of the approaches examined offers a broad view of the issue. As for undiscovered references, it is possible that some interesting works have not been addressed; probably "grey literature" (McAuley, Tugwell, & Moher, 2000).

5. Conclusions

The application of neuroscience to architecture is gaining prominence. The term "neuroarchitecture", seems to work in a promotional sense, probably, in part, due to the tendency to consider neuroscientific content credible (Keehner & Fischer, 2011). However, it does not seem appropriate at other levels: computerised searches (mixed with neural architectural issues or artificial intelligence); conceptual (does not do justice to neuroscience or architecture); and technical (does not make clear if it includes works not strictly based on neurophysiological recordings). The ease in translating the term into different languages, and the amount of documentation generated, makes it difficult to adopt perhaps more appropriate terms, such as "emotional architecture", or "mental architecture".

In another vein, neuroarchitecture is often decontextualized, without considering its main precursor approaches. This creates biases about its current possibilities and future developments and, as with social sciences (Fitzgerald & Callard, 2015), neuroscientific applications generate some controversy. From some conservative points of view, accepting external guidelines infringes on issues deeply established in the project process. Most of the changes generate neophobic impulses, and the advent and development of neuroarchitecture may mark a paradigm shift. However, the application of neuroscience to architecture is not intended to reduce design to universal standards. Understanding the fundamentals on the cognitive-emotional dimension of architecture does not make it less relevant. Nor will it remove the need for architects, it will only complement their tool set, that already includes tools (more or less used in practice), such as geometry, phenomenology, geographical experience, philosophy and, more recently, psychological and EBD approaches. The knowledge offered by neuroarchitecture will help more broadly meet users' needs. A building might not collapse due to poor cognitive-emotional adaptation, but its users might. Although it will take years to design projects entirely using principles and knowledge derived from neuroscientific explorations of the built environment, we can today take steps to improve the human cognitive-emotional response in the built architectural environment; this includes modifying existing spaces and improving decision making for the design of new spaces. The combination of advances in neuroscience and environmental simulation will expand the impact of the new discipline. The next great architects may be those who can embrace, without prejudice, these new possibilities. The challenge looks exciting.

04
Artículo 4
Paper 2

"Psychological and physiological human responses to simulated and real environments: A comparison between photographs, 360 panoramas, and virtual reality".

Este artículo fue publicado en la revista "Applied Ergonomics" (ISSN 0003-6870). Es una revista internacional, revisada por pares (siguiendo una double-blind review), sobre la aplicación de la ergonomía y los factores humanos en el diseño. En concreto, forma parte del *special issue* "New technologies in human factors and ergonomics research and practice". Este número especial incluye aplicaciones de las nuevas tecnologías interactivas en la investigación de la ergonomía y los factores humanos. La revista tiene lectores de diferentes áreas de conocimiento; entre ellas: ergónomos, diseñadores, ingenieros industriales, y psicólogos. Así, la revista "Applied Ergonomics" es referente en áreas de conocimiento como la ergonomía o la psicología aplicada; estando indexada en SJR (Q1 – 1.071 en 2017, año de su publicación; categorías como "social sciences" y "engineering") y JCR (Q1 - 2.435 en 2017; categorías "ergonomics" - 2/16; "psychology applied" - 25/82; y "engineering, industrial" - 16/47). Según Google Scholar, hasta la fecha este artículo ha sido citado 84 veces.

Higuera-Trujillo, J. L., López-Tarruella, J., & Llinares, C. (2017). Psychological and physiological human responses to simulated and real environments: A comparison between photographs, 360 panoramas, and virtual reality.
Applied Ergonomics, *65*, 398-409.
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This paper was published in the journal "Applied Ergonomics" (ISSN 0003-6870). It is an international, peer-reviewed journal (following a double-blind review) on the application of ergonomics and human factors in design. Specifically, it is part of the special issue "New technologies in human factors and ergonomics research and practice". This special issue includes applications of new interactive technologies in ergonomics and human factors research. The journal has readers from different areas of expertise, including ergonomists, designers, industrial engineers, and psychologists. Thus, the journal "Applied Ergonomics" is a reference in areas of knowledge such as ergonomics or applied psychology; being indexed in SJR (Q1 - 1,071 in 2017, year of publication; categories such as "social sciences" and "engineering") and JCR (Q1 - 2,435 in 2017; categories "ergonomics" - 2/16; "applied psychology" - 25/82; and "engineering, industrial" - 16/47). According to Google Scholar, this paper has been cited 84 times to date.

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Abstract

Psychological research into human factors frequently uses simulations to study the relationship between human behaviour and the environment. Their validity depends on their similarity with the physical environments. This paper aims to validate three environmental-simulation display formats: photographs, 360° panoramas, and virtual reality. To do this we compared the psychological and physiological responses evoked by simulated environments set-ups to those from a physical environment set-up; we also assessed the users' sense of presence. Analysis show that 360° panoramas offer the closest to reality results according to the participants' psychological responses, and virtual reality according to the physiological responses. We also observed correlations between the feeling of presence and physiological and other psychological responses. These results may be of interest to researchers using environmental-simulation technologies currently available in order to replicate the experience of physical environments.

1. Introduction

Environmental simulations acquire a relevant role in environmental psychology as they allow us to recreate and study in isolation and in a controlled way the effects of space on human experience (Sheppard & Salter, 2004). The validity of these simulations is related to its capacity of evoking a participant's response similar to the one that the space it is simulating would (Rohrmann & Bishop, 2002). This logic is based on 'behavioural realism': the context in which an environmental simulation is better the more similar the user will respond to it compared to the represented environment (Freeman et al., 2000). In this sense, new environmental representation technologies address this issue through the improvement of the sense of presence, (Sanchez-Vives and Slater, 2005), the visual experience (Lovett et al., 2015), and the interaction with the represented spaces, allowing users to freely act within them (Appleton et al., 2002).

Overall published validity results show that simulations tend to evoke a user's response similar to those for physical environments (Villa & Labayrade, 2012). However, these studies have some limitations, being one of the main ones obsolescence of the studied systems: the constant proliferation and iteration of these technologies (Rohrmann & Bishop, 2002) reveal the importance of critically and comparatively updating the validity of the main formats for the most common current platforms (de Kort et al., 2003). Another serious limitation concerns the neglect of some subjective aspects of user experience: the majority of studies compare responses in terms of preference, without deepening into the set of cognitive-emotional psychological states behind it (Bishop and Rohrmann, 2003). A third limitation stems from the scarcity of studies incorporating the subject's objective response in the validation. Given that most estimation, thought, emotion, and learning are produced at the unconscious level (Zaltman, 2003), validity studies must be performed using new metrics and methods to measure these components (Gill, Lange, Morgan, & Romano, 2013). Thus, traditional scientific measurements may not be sufficient to evaluate new and future platforms (Orland, 2015) and so, any validation of these new systems should address these limitations.

The present work aims to respond to the previously mentioned limitations in order to validate environmental simulation display formats (photograph, 360° panorama, and virtual reality) through subjective judgements (psychological) and objective measures (physiological). Thus, the fundamental goal of the study is to understand which one of the three display formats gives the closest approximation of experience in physical environments by carrying out a comparative validation. Specifically, the questions that we intend to address are twofold: (a) are psychological and physiological responses evoked to the simulations similar to those resulting from exposure to physical environment? and (b) are these simulations capable of generating a strong sense of presence? These results may be of interest to researchers using environmental-simulation technologies currently available to replicate the experience of physical environments.

1.1. Background Research

This section compiles aspects related to the research background: (1) simulated environments display formats; (2) psychological human response; (3) physiological human response; and (4) physiological human response.

1.1.1. Simulated environments display formats

Simulation tools are becoming rapidly incorporated into human factors fields (like military training, medical education and improvement of the industrial processes) because of their scientific and commercial possibilities through a combination of new platforms and formats (Lange, 2001). The most used formats in environmental simulations are photography and Virtual Reality (VR).

Photography captures physical-world images using light. Within this format one must differentiate between photograph and 360º panorama. The former is the most widely used because of its visual realism capabilities and ease of use. The validity of this format has also been extensively explored (Stamps, 1990), especially in landscape studies (Hull IV & Stewart, 1992), in which strong correlation has been identified between psychological responses and physical environments. This format, typically displayed by means of printed images and more and more often by means of screens, represents a possible limitation: the distortion of the user's response because of the effect of certain environmental factors such as noise or visual distractions. Nowadays there exist display systems which eliminate this effect, such as the head-mounted display (HMD). This is a fully-immersive system which allows us to isolate the user's senses from the external world. A higher degree of immersion provokes a greater sense of presence, understood as a perceptual illusion of non-mediation, only quantifiable by the user experiencing it (Baños et al., 2004; Diemer et al., 2015). Despite HMD has been designed to visualize other types of formats, such as 360º panorama or VR, also allows to visualize photographs. 360º panorama is currently widespread in environmental simulation (Jacobs, 2004) and allows interesting syncretism between photographic techniques and VR (such as Google Street View), making them more interactive, and even immersive when combined with a HMD. However, regarding its validity, no research analogues have yet been developed and so it has only been assessed in terms of spatial knowledge acquisition by using desktop and HMD simulations (Napieralski et al., 2014a).

VR offers the possibility of generating computer representations which give the feeling of 'being there' (Steuer, 1992) in an interactive environment which overrides the other sensory information the user receives. In this way, VR acquires a relevant role in certain fields in which the interaction is important, such as medicine (Jack et al., 2001), product design (Ye, Badiyani, Raja, & Schlegel, 2007), environment design (Frost & Warren, 2000) or education (Germani, Mengoni, & Peruzzini, 2012). However, despite its increasing implementation in different fields, the studies which mention its validity are still scarce: for example, studies focusing on projection platforms (de Kort et al., 2003), qualitative research at the behavioural level using a desktop platform (Murray, Bowers, West, Pettifer, & Gibson, 2000), and although not interactively, work on computer-generated videos (Bishop & Rohrmann, 2003). Another interesting studied effect in this validation of the VR is the possible effect between environment and presentation order (Kuliga, Thrash, Dalton, & Hölscher, 2015). In general, the results show that there are no significant differences in psychological user's responses compared to those evoked by physical environments, although further research is still required (Lange, 2011). At another level, we also found studies comparing features of VR-based set-ups: screen size, stereoscopy, and field of view, etc., in terms of their effects on understanding and presence (Zikic, 2007), the level of detail or realism in spatial understanding (Nikolic, 2007) or the comparison between different set-ups based on a set of metric performances for mechanical design learning (Mengoni et al., 2011).

1.1.2. Psychological human response

Within the psychological measurements, the Küller and Mehrabian–Russell models stand out; these describe the affective and emotional states related to the impact the environment has on individuals. On the one hand, there are eight Küller dimensions: affection, complexity, enclosedness, originality, pleasantness, potency, social status, and unity (called "SMB", from Swedish "Semantisk Miljö Beskrivning" meaning semantic environmental scale; for further description see: Küller, 1991, 1980). These dimensions have been used for very different purposes, such as analysing diverse workspaces (Janssens & Küller, 1989), evaluating the effect of colour in these spaces (Mikellides, 1989), or comparison of different traditional environmental simulation set-ups during planning and design (Jan Janssens & Küller, 1986). On the other hand, there are three Russell–Mehrabian emotional dimensions: pleasure, arousal, and dominance (called "PAD" emotional state model, for a more complete description see: Mehrabian, 1989). These currently form part of a widely accepted conceptual framework on emotion (Plutchik & Kellerman, 1980). The first applications of these dimensions were in environmental psychology, and they have been widely accepted in architecture studies (Gifford et al., 2000; Higuera-Trujillo et al., 2017). Moreover, they have been extended to applications such as the design of avatars in the VR field (S. Zhang, Wu, Meng, & Cai, 2007) and the creation of virtual spaces capable of evoking emotional states in a controlled way (McCall et al., 2016). Therefore, both models are fundamental for assessing psychological judgments of spaces.

Another issue for the psychological analysis of simulated-environments is presence, which is usually measured via post-activity questionnaires (Slater & Wilbur, 1997). While there are other means to measure this aspect such as psychophysical or qualitative methods, questionnaires are the most commonly used because of the advantages they present: validity, low cost, and ease of management and analysis. One of the most widely used is the SUS questionnaire (after Slater, Usoh, and Steed; for further description see: Slater et al., 1994) which measures the extent of three aspects: the participant's sense of being inside the simulated environment, the degree to which the environmental simulation is considered the dominant reality, and how far the simulated environment is remembered as a place (Usoh et al., 2000). The current version of the questionnaire consists of six items rated on a Likert scale of 1 to 7, and the final score is taken as the absolute number of items which scored 6 or 7 (i.e. score range 0-6). This questionnaire has been used in studies on the relationship between presence and performance in VR (Youngblut & Perrin, 2002) and in comparisons between the level of immersion using different platforms (Juan & Pérez, 2009; Slater, Sadagic, Usoh, & Schroeder, 2000).

1.1.3. Physiological human response

Knowledge of the human response to the environment can be completed by using physicological measurements (Reinerman-Jones et al., 2013). In this regard, Izar (1992) argues that cognitive-emotional states are characterised by both psychological and physiological responses. This registration capability is especially relevant when considering that going beyond concious control (Winkielman et al., 2001) is more objective than self-reporting (Reinerman-Jones et al., 2010). There are different techniques for registering this response which cover the central, autonomous, and somatic nervous systems (Bagozzi, 1991).

In our case, we decided to study the autonomous nervous system, and specifically electrodermal activity (EDA) and electrocardiogram (ECG) measurements, because, besides being able to capture response patterns in emotion (Kreibig, 2010), they have other greater advantages for the purposes of studying validity. In particular, these techniques can register measurements through portable and minimally-invasive devices, and altogether they quantitatively record sympathetic and parasympathetic nervous system activity related to the generation of states of activation and relaxation, respectively (McCorry, 2007).

EDA measures variation in electrodermal properties resulting from sweat generation (Boucsein, 2012). Although sudomotor activity plays an important role in other bodily processes, it is also related to sympathetic activity (Dawson et al., 2007). Its analysis allows us to break it down into: slowly-varying tonic activity, which refers to the basal level of conductance; and fast-varying phasic activity, concerning responses to stimuli. Among previously published work using this terminology, some studies have identified an increase in tonic (Ritz, Steptoe, DeWilde, & Costa, 2000) and phasic activity (Blechert, Lajtman, Michael, Margraf, & Wilhelm, 2006) when users were presented aspects related to arousal, with phasic activity sometimes receiving greater interest (Braithwaite, Watson, Jones, & Rowe, 2013). In contrast, ECGs are the graphic representations of electrical heart activity (Goldman, 1976). Heart Rate Variability (HRV) can be calculated from this data, and the analysis of the frequency domain can be broken down into two subsets: high frequency or HF (0.15-0.4 Hz), widely accepted as being related to parasympathetic nervous system activity, and low frequency or LF (0.04-0.15 Hz), which, although more complex, is related to the sympathetic nervous system (Berntson et al., 1997). This recording system has previously been used to observe responses to the valence of certain stimuli (Rantanen et al., 2013) and aspects related to arousal, resulting in a relationship being identified between increased Heart Rate (HR) (Adsett, Schottsteadt, & Wolf, 1962) and LF domain (Murakami & Ohira, 2007). However, to date, neither EDA nor HRV have been used to study the validity of environmental simulations, they have been used in VR studies. Thus, EDA has been used as a metric to examine the effect of certain affective states in generating the feeling of presence (Felnhofer et al., 2015), and HRV has been used to study the influence of virtual- or physical-category stimuli in generating stress (Kothgassner et al., 2016). Given that registry of these responses is compatible with those offered by traditional metrics (Reimann et al., 2010), there is reason to believe that they could provide deeper insight in validation studies.

2. Materials and Methods

The experiment was conducted in a single session and aimed to uncover the extent to which different display formats produce the same user response as a physical environment. Table 4.1 presents a summary of the experiment divided into two phases, each one corresponding to a different objective. Phase 1 is focused on the analysis of the psychological and physiological responses. For this purpose, we used SMB and PAD psychological models, and EDA and HRV physiological measurements. Phase 2 comprises the analysis of presence by means of SUS presence questionnaire. For the development of the experience four environmental set-ups were generated (physical environment, photograph, 360° panorama, and VR). A display system compatible with the three display formats to be compared with the physical environment was selected: head-mounted display.

Table 4.1. Summary of the experiment.

	Phase 1. Are responses to the simulations similar to those evoked when exposed to physical environment?			**Phase 2. Presence**
Phase	a. Are subjective responses to the simulations similar to those evoked when exposed to physical environment?	b. Are objective responses to the simulations similar to those evoked when exposed to physical environment?	c. Are physiological responses capable of predicting psychometric responses?	Are simulated environments capable of generating a level of Presence similar to the physical environment?
Stimuli	Shopping Environment			
Display Format	Physical Environment / Photograph / 360° Panorama / Virtual Reality			
Display System	Samsung Gear VR Head-Mounted Display			
Dependent Variables	SMB PAD	Electrodermal Activity Heart Rate Variability	Correlation of EDA and HRV to the SMB and PAD	SUS Presence Test
Material	Survey	Empatica E4 wristband		Survey
Analysis	Mean analysis Mann–Whitney U test	Mean analysis Mann–Whitney U test	Partial correlation	Mean analysis Partial correlation

2.1. Environment Set-Ups

We selected an interior shopping environment, because previous work has already evaluated the realism of this type of environment and the employed questionnaires had already been validated (Machleit and Eroglu, 2000; Stone and Congdon, 2007). This environment is also sufficiently complex to evaluate spatial features, and its dimensions and characteristics make it ideal for generating a virtual environment.

Hereunder we describe the fundamental characteristics of the different environment set-ups used, being set-up understood as the group of technological devices, display format and interaction modality forming each experience.

- Physical environment set-up: a physical mock-up of the environment was built in our research space; this comprised a 4.5m × 4.5m white room with a door, a window, and two sales shelves opposite to each other containing several beer brands. Participants walked freely all over the physical environment.
- Photograph environment set-up (Figure 4.1, part A): a monoscopic digital photograph with a resolution of 1280 × 720 pixels, taken with a GoPro Hero3+Silver camera. The shot was taken in the centre of the mock-up room at a height of 165 cm to simulate eye level. As technological device, a Samsung Gear VR HMD was used. Due to the fact that the ability of traditional photography to capture the entire environment and to interact is limited, the most representative viewpoint was chosen (Hetherington et al., 1993)
- 360º panorama environment set-up (Figure 4.1, part B): a 360° × 180° equirectangular monoscopic photograph with a total resolution of 4096 × 2048 pixels, based on photographs taken with seven GoPro Hero 3+Silver cameras coupled to a stationary base for panoramic recording. Shot was taken in the same position and height as the one used for the standard photograph. As technological device, a Samsung Gear VR HMD was used. The participant's interaction consisted on the tracking of the head orientation by means of the gyroscopes and accelerometers of this device.
- VR environment set-up (Figure 4.1, part C): an interactive tridimensional simulation developed by means of the Unity game engine (Unity3D 5.1; https://unity3d.com/). The model was generated in SketchUp 2015 (http://www.sketchup.com), and the textures were extracted from the physical environment to achieve maximum realism. The designed environment contained 15.546 polygons and 112 textures. As technological device, a Samsung Gear VR HMD was used. Participant's interaction consisted on the tracking of the head orientation of this device, and the navigation all over the environment using a wireless joystick.

As it has already been mentioned, a HMD was used in these experiments. It is a fully-immersive virtual environment, following Rangaraju and Terk's classification (2001), which isolates the user's senses from the external world, generating the greatest sense of presence and immersion in the user. This display system has rapidly evolved in the last few years, being no longer difficult to control nor expensive devices (Parsons, 2015). This explains why HMDs are becoming protagonists in the ongoing emergence of several different applications (Javidi and Tekalp, 2017). In this study, the main advantage is that they enable us to comparatively validate three display formats regarding the physical environment, as it they homogenize the experience with regard to the display system used. Specifically, as technological device a Samsung Gear VR was used because of its portability. It consistes of a mobile VR headset with a stereoscopic screen (1280 × 1440 pixels per eye), 96° field of view, supported by a Samsung Note 4 mobile telephone with a 2.7GHz quad-core processor and 3GB of RAM.

Figure 4.1. Views from A) Photograph, B) 360º Panorama, and C) Virtual Reality scenarios.

2.2. Dependent Variables

Different sets of variables were assessed within each phase and they were evaluated in the same sequence for the four set-ups (three format displays and physical environment), except the presence analysis, which was not employed in the evaluation of the physical environment. A summary of the questions asked for each phase of the experiment is presented in Table 4.2.

Table 4.2. Summary of the questions posed in different phases of the dependant variable assessment.

SMB scale for environmental assessment *(photograph, 360º, VR, physical env.)*		Rate the shopping space in terms of:
	1	Pleasantness: The environmental quality of being pleasant, beautiful and secure
	2	Complexity: The degree of variation or, more specifically, intensity, contrast, and abundance
	3	Unity: How well all the various parts of the environment fit together into a coherent and functional whole
	4	Enclosedness: A sense of spatial enclosure and demarcation
	5	Potency: An expression of power in the environment and its various parts
	6	Social Status: An evaluation of the built environment in socioeconomic terms
	7	Affection: The quality of recognition giving rise to a sense of familiarity
	8	Originality: The unusual and surprising in the environment
PAD emotional state model *(photograph, 360º, VR, physical env.)*		Rate your state in terms of:
	1	Pleasure: how pleasant or unpleasant you feel about the space
	2	Arousal: how energized or soporific you feel due to the space
	3	Dominance: How controlling versus controlled you feel due to the space
SUS Presence questionnaire *(photograph, 360º, VR)*		Rate:
	1	Your sense of being in the space, being 1. Not at all ... 7. Very much
	2	To what extent were there times during the experience when the shopping space was the reality for you? being 1. At no time ... 7. Almost all the time
	3	When you think back about your experience, do you think of the shopping space more as images that you saw, or more as somewhere that you visited?, being 1. Images that I saw ... 7. Somewhere that I visited
	4	During the time of the experience, which was strongest on the whole, your sense of being in the shopping space, or of being elsewhere? being 1. Being elsewhere ... 7. Being in the shopping space
	5	Consider your memory of being in the shopping space. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? being 1. Not at all ... 7. Very much so
	6	During the time of the experience, did you often think to yourself that you were actually in the shopping space? being 1. Not very often ... 7. Very much so

2.2.1. Phase 1. Analysis of the Psychological and Physiological responses

The analysis of psychological and physiological responses is specified below.

a) Analysis of the psychological response

A questionnaire was designed to collect two data sets on a 7-point Likert scale: the first consisted of the eight affective appraisal dimensions from the SMB scale, and the second comprised the three dimensions from the PAD emotional state model.

b) Analysis of the physiological response

We measured EDA and HR signals in this experiment by using a portable physiological wristband device (E4 wristband, Empatica; www.empatica.com). EDA data was sampled at 4Hz (0.001-100 μS) and HR was acquired at 64Hz by photoplethysmography.

2.2.2. Phase 2. Analysis of Presence

The validated SUS presence questionnaire consisted of six items on a 7-point Likert scale and it was used to assess the participants' sense of presence in each display format.

2.3. Participants

One hundred individuals took part in the study; the participants were balanced in terms of age (23-51 years, μ = 32.68, σ = 7.00) and gender (54% male, 46% female). The required number of participants was determined using statistical methods (Faul et al., 2007), calculations indicating that 25 respondents per stimuli would be sufficient to achieve the desired alpha and beta error levels. In this way, a group of 25 different subjects was set to evaluate every set-up.

The selection criteria were that participants must not be familiar with the scenes or suffer from claustrophobia, epilepsy, or nausea because three-dimensional immersion technologies can be harmful in such cases (Sharples et al., 2008). During the physiological signal acquisition, some data were lost (because of participant movement or wristband failure) resulting in a lower final sample number.

2.4. Procedure

The individuals were given a brief explanation of the experiment and signed their informed consent to participate. They were then instructed on how to use the technology, and those assigned to the VR format practised moving through the virtual 3D environment (a room without furniture or decorations specifically designed for this training) so they could get used to navigate it before starting the experiment.

At the beginning of the study, each participant sat down, put on the E4 wristband, switched it on, and listened to a two-minute relaxing audio through headphones to create a common state of baseline calm. When the audio ended, the subjects stood up and they were shown the assigned scenario (either they were placed the HMD in case of photograph, 360º panorama and VR, or they were accompanied to an adjoining room where the physical set-up was located). In any case the subject was standing during the assessment of the set-up.

The stimulus was always starting at the same point and angle of vision, and the participants examined the environment in detail for three minutes. During this time, the subject explored the space on unconstrained gaze and movement, taking into account the possibilities offered by the set-up to be evaluated. In this manner, the subjects evaluating the photograph could only visualize; the ones evaluating the 360º panorama could visualize other angles from the same point of view; the ones evaluating VR could navigate all over the environment; and the ones evaluating the physical environment walked freely all over the space.

Finally, after three minutes and while the subject was still looking at the stimulus, the researcher orally asked the questions on the questionnaire.

2.5. Data analysis

The pre-processing of physiological responses and statistical analysis is specified below.

2.5.1. Physiological data pre-processing

For each participant, the raw EDA and HR data were gathered both during the relaxing audio (baseline) and stimuli visualisation.

The EDA signals were pre-processed and analysed with an EDA analysis toolbox (Ledalab® V3.4.8, www.ledalab.de), run in Matlab (2012a; www.mathworks.com). Pre-processing consisted on a visual diagnostic of artefacts and their corrections. Continuous Decomposition Analysis (Benedek and Kaernbach, 2010) was used applied to the cleaned signal to extract the phasic component. Data was exported into Matlab for each participant and condition (baseline and stimuli) to calculate the means and standard deviations. To reduce inter-subject differences all the values were standardised using an adaptation of the Venables and Christie formula "y = log(1+|x|)·sign(x)" (Venables and Christie, 1980).

HR signals were pre-processed and analysed using a HRV analysis toolbox (HRVAS V2014-03-21), run in Matlab. The Welch method for frequency analysis (Welch, 1967) was used to calculate the absolute values for each participant and condition for the HF (0.15-0.4 Hz) HRV band, expressed in normalised HF (nHF) units (Camm and Malik, 1996) which are correlated with parasympathetic activity (Berntson and Cacioppo, 2004).

Once that Phasic-EDA and nHF-HRV mean values were computed for each participant and condition (1. baseline and 2. stimuli), every stimulus value was standardised over its previous baseline value to acquire individual *within subject* variations that could be exported to our statistical software package. The final values for each participant are:

- Phasic-EDA = (mean Phasic-EDA stimuli / mean Phasic-EDA baseline)
- nHF-HRV = (mean nHF-HRV stimuli / mean nHF-HRV baseline)

Therefore, these two variables represent the response before application of the stimulus in proportion to the pre-stimulus baseline.

2.5.2. Statistical analysis

Both the questionnaire and pre-processed psychophysiological data were imported into SPSS (v.22) for statistical analysis.

For Phase 1, average dependent variable values were standardised over "physical" stimuli values to simplify the comparison between different display formats. In this way, these measurements show if the dependent variables for each display format are rated over or under the physical environment. Furthermore, the average of these values was obtained in absolute value, to indicate global accuracy (the more accurate the format, the closer it is to 0). This value was labelled as "closeness".

Non-parametric Mann–Whitney U tests were carried out to identify any statistically significant differences between each pair of simulation and "physical" condition data. Finally, partial correlation, controlling for the "stimuli" variable, was executed to examine possible relationships between the psychological and physiological responses.

For Phase 2, presence data were treated according to the Slater, Usoh and Steed methodology: the "SUS presence" score is taken as the absolute number of answers that have a score of 6 or 7 (from six questions rated from 1 to 7), to produce a final score ranging from 0 to 6 which was standardised to a 0-1 range. In addition, because the SUS presence score manipulates data in a non-linear way, in order to examine correlations with it, a direct score (presence) was recorded by summing all values from the presence questionnaire (ranging from 6 to 42) and standardising them to a 0-1 range.

3. Results

This section presents the results of the study for Phase 1 and Phase 2.

3.1. Phase 1. Comparison of Psychological and Physiological Responses to the Physical Environment Analysis of psychological responses

The results of Phase 1 include analyses on: (1) the psychological response, (2) the physiological response, and (3) the relationship between psychological and physiological responses.

3.1.1. Analysis of psychological responses

Figure 4.2 shows the means for each variable (eight affective attributes and three emotional factors) and format analysed in relation to 'physical' environment (all values were standardised to the "physical" values: mean = 0 and SD = 1). Overall, the 360° panorama tends to slightly overestimate values for the physical environment (the 'potency' and 'originality' values stand out) while VR and, especially, the photograph, tends to underestimate them. Moreover, all the formats clearly overestimated 'arousal' and underestimated "dominance" compared to the values for the physical environment. The 'closeness' score was 0.38 for the 360° panorama, 0.53 for VR, and 0.93 for the photograph, which gives the accuracy rank in relation to the physical environment.

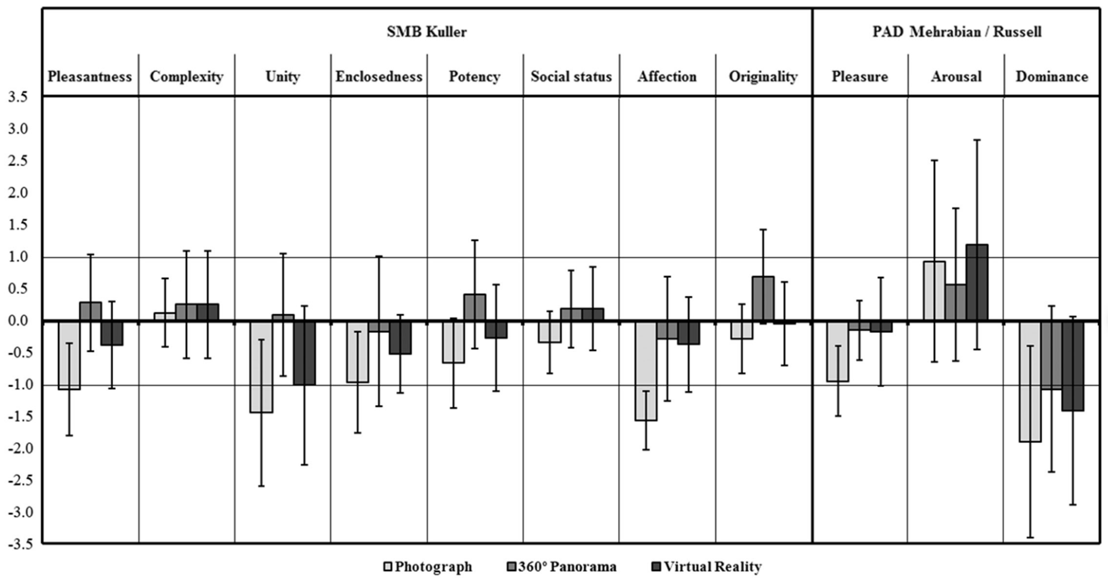

Figure 4.2. Psychological responses to the Photograph, 360° Panorama, and Virtual Reality set-ups based on the SMB and PAD. Means standardised in relation to physical environment in which mean = 0 and SD = 1.

The paired Mann–Whitney U tests also found statistically significant differences in two out of eleven factors for the 360° panorama, four for VR, and eight for the photograph (Table 4.3). Thus, regarding affective attributes, participants' responses significantly differed from that evoked by the physical environment only in 'Originality' for the 360° panorama, 'Unity' and 'Enclosedness' for VR, and 'Pleasantness', 'Unity', 'Enclosedness', 'Potency', and 'Affection' for the photograph. In relation to emotional factors, participants' responses significantly differed from that produced by the physical environment only in 'Dominance' for the 360° panorama, 'Arousal' and 'Dominance' for VR, and 'Pleasure', 'Unity', 'Arousal', and 'Dominance' for the photograph.

Table 4.3. Differences between the psychological responses to the photograph, 360° panorama, and virtual reality set-ups compared the response evoked by the physical environment set-up.

		SMB								PAD		
		Pleas-ant-ness	Com-plexity	Unity	En-closed-ness	Poten-cy	Social status	Affec-tion	Origi-nality	Plea-sure	Arousal	Domi-nance
Photo-graph vs Physical env.	U - Mann–Whitney	117.00	248.00	111.00	150.00	197.00	266.00	49.00	293.00	126.00	*201.00*	87.00
	W - Wil-coxon	442.00	573.00	436.00	475.00	522.00	591.00	374.00	618.00	451.00	*526.00*	412.00
	Z	-3.89	-1.30	-4.06	-3.29	-2.31	-0.95	-5.20	-0.39	-3.70	*-2.31*	-4.51
	Signifi-cance	0.00	0.19	0.00	0.00	0.02	0.34	0.00	0.69	0.00	0.02	0.00
360° Panora-ma vs Physical env.	U - Mann–Whitney	261.50	246.50	300.00	294.50	224.50	247.50	252.50	179.50	285.00	*224.5*	175.50
	W - Wil-coxon	586.50	571.50	625.00	619.50	549.50	572.50	577.50	504.50	610.00	*549.5*	500.50
	Z	-1.02	-1.32	-0.26	-0.36	-1.74	-1.29	-1.21	-2.62	-0.56	*-1.82*	-2.77
	Signifi-cance	0.31	0.19	0.79	0.72	0.08	0.20	0.23	0.01	0.58	0.07	0.01
Virtual Reality vs Physical env.	U - Mann–Whitney	234.00	249.50	171.50	208.50	280.00	246.00	226.50	294.50	284.50	*170.0*	135.00
	W - Wil-coxon	559.00	574.50	496.50	533.50	605.00	571.00	551.50	619.50	609.50	*495.0*	460.00
	Z	-1.58	-1.25	-2.87	-2.14	-0.65	-1.33	-1.72	-0.36	-0.56	*-2.89*	-3.55
	Signifi-cance	0.11	0.21	0.00	0.03	0.52	0.18	0.09	0.72	0.58	0.00	0.00

3.1.2. Analysis of physiological responses

Figure 4.3 shows the means for the Phasic-EDA and nHF-HRV for every format analysed in relation to the 'physical' environment (all values were standardised to the 'physical' values: mean = 0 and SD = 1). The 'closeness' score was 0.08 for VR, 0.36 for the 360° panorama, and 0.46 for the photograph, which gives the accuracy rank in relation to physical environment.

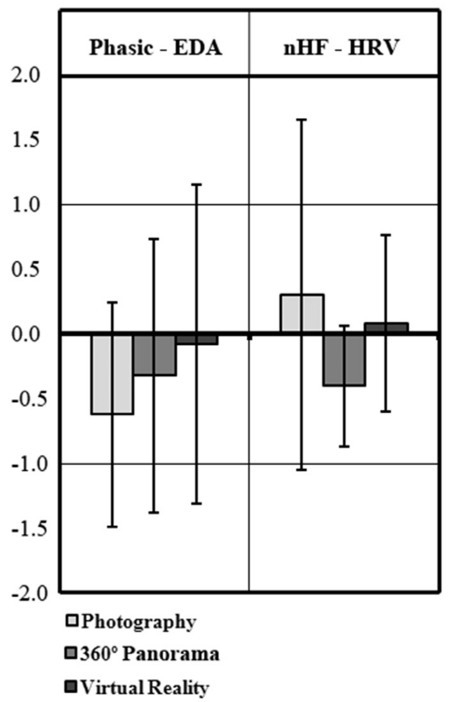

Figure 4.3. Physiological responses to the Photograph, 360° Panorama, and Virtual Reality set-ups. Means are standardised in relation to the responses evoked by the physical environment in which mean = 0 and SD = 1.

The paired Mann–Whitney U tests (Table 4.4) also found a statistically significant difference between the photograph and physical environment in the Phasic-EDA component.

Table 4.4. Differences between physiological responses to the photograph, 360° panorama, and virtual reality set-ups compared to the responses evoked by the physical environment set-up.

		EDA Phasic	HRV nHF
Photograph vs Physical env.	U - Mann–Whitney	152.50	117.50
	W - Wilcoxon	405.50	237.50
	Z	-2.45	-0.63
	Significance	0.01	0.53
360° Panorama vs Physical env.	U - Mann–Whitney	216.00	113.00
	W - Wilcoxon	541.00	303.00
	Z	-1.68	-1.02
	Significance	0.09	0.31
Virtual Reality vs Physical env.	U - Mann–Whitney	275.50	114.00
	W - Wilcoxon	600.50	234.00
	Z	-0.49	-0.51
	Significance	0.62	0.61

3.1.3. Analysis of the relationship between psychological and physiological responses

Partial correlation between the psychological and physiological responses, controlling for the "stimuli" variable (Table 4.5), identified relationships between Phasic-EDA and 'pleasantness' (ϱ = 0.426, α = 0.002), "enclosedness" (ϱ = -0.331, α = 0.016), and 'pleasure' (ϱ = 0.314, α = 0.023). No correlations were found for nHF-HRV.

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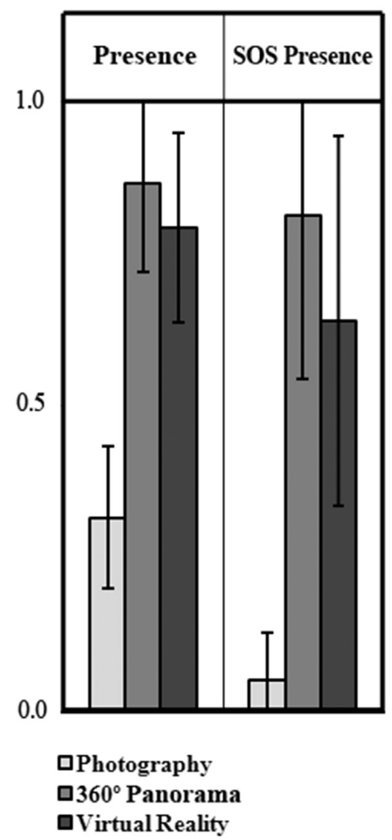
Table 4.5. Correlations between the psychological and physiological responses, identified by partial correlation analysis, controlling for the "stimuli" variable

		SMB								PAD		
		Pleasantness	Complexity	Unity	Enclosedness	Potency	Social Status	Affection	Originality	Pleasure	Arousal	Dominance
Phasic EDA	Coef.	0.426	-0.038	-0.092	-0.331	0.040	0.034	0.057	0.207	0.314	-0.031	-0.064
	Sig.	0.002	0.789	.0518	0.016	0.781	0.810	0.688	0.141	0.023	0.826	0.650
nHF HRV	Coef.	0.155	-0.045	-0.237	-0.178	0.034	0.073	-0.031	-0.126	0.268	0.027	0.050
	Sig.	0.273	0.754	0.091	0.207	0.809	0.606	0.829	0.372	0.055	0.847	0.726

3.2. Phase 2. Analysis of Presence

Figure 4.4 presents the unitarized means (the sum of the answers to the six questions) for 'presence' and the 'SUS presence' (the absolute number of answers with a score of 6 or 7). The 360° panorama produced the highest sense of presence, closely followed by VR, and finally, by the photograph which had an extremely low score.



The partial correlation test (Table 4.6) also identified relationships between 'presence' and SMB scale 'pleasantness' (ϱ = 0.333, α = 0.016), 'potency' (ϱ = 0.348, α = 0.011), 'social status' (ϱ = 0.278, α = 0.046), and 'originality' (ϱ = 0.448, α = 0.001), as well as an inverted correlation between 'presence' and physiological nHF-HRV (ϱ = -0.348, α = 0.012).

Figure 4.4. Mean Presence for the Photograph, 360° Panorama, and Virtual Reality set-ups, as measured on the SUS (after Slater, Usoh and Steed) scale.

Table 4.6. Correlations between presence and SMD-PAD and EDA-HRV responses identified using a partial correlation test.

	Psycometric											Physiological	
	SMB								PAD			EDA	HRV
Presence	Pleasantness	Complexity	Unity	Enclosedness	Potency	Social Status	Affection	Originality	Pleasure	Arousal	Dominance	Phasic	nHF
Coef.	0.333	0.153	0.255	0.175	0.348	0.278	0.216	0.448	0.021	-0.120	0.014	0.123	-0.348
Sig.	0.016	0.280	0.068	0.216	0.011	0.046	0.124	0.001	0.882	0.398	0.923	0.383	0.012

4. Discussion

The purpose of this research was to comparatively validate three of the most common traditional and current environmental-simulation display formats: photograph, 360° panorama, and VR via an innovative HMD. With this aim in mind, we designed this study to assess both psychological and physiological human responses to environmental simulations compared to physical environments, and the sense of presence felt in these environments.

Psychology research into human factors frequently uses simulations instead of physical environments to assess psychological and physiological responses to environments. Although no platform or format can exactly reproduce physical environment (Moscoso et al., 2015), these environmental simulations have clear advantages for scientific purposes in controlled conditions. The validity of these simulations depends on the similarity of their results to those acquired by physical environment. Although there are many studies comparing display formats and systems, i.e. traditional vs. rendered images (Bates-Brkljac, 2009), images vs. videos (Stamps III, 2007), videos vs. virtual environments (Conniff et al., 2010), videos vs. physical experiences (Bishop and Rohrmann, 2003), or even different factors from a particular system such as screen size, stereoscopy, field of view (Zikic, 2007), level of detail, or realism (Nikolic, 2007), we could not find any studies that compare the generated response by the same simulated environment by means of different formats. Moreover, simultaneously recording both psychological and physiological responses, a fundamental aspect of studying the relationship between people and their environments (Küller, 1991), has not been seen previously used in this type of validation study. Thus, the fundamental contribution of this work lies in its combined technological and methodological innovations.

Specifically, the findings of this study are outlined in the following three main outcomes:

Firstly, we note that the 360° panorama and VR formats more closely approach the physical environment, both in terms of psychological and physiological responses, compared to the photograph. This may be because the participants could look around these environments, thus increasing their sense of presence (Alshaer et al., 2017). Regarding the psychological responses, 360° panorama led to the most accurate outcomes; this may be also linked to increased participants' presence, because it has previously been related to deeper emotional response (Riva et al., 2007). Concerning physiological responses, the VR format reached the closest approximation to physical life conditions, which may be due to the influence that interactivity has on the sense of presence (Haans and Ijsselsteijn, 2012), as there have been proven effects of free navigation at a neurophysiological level (Clemente et al., 2014). Therefore, VR appears to be the most appropriate display when trying to evoke physiological responses in environmental studies (Rodríguez et al., 2015). Finally, the photograph format is the farthest from physical environment; although it is the most widely used format in environment-behaviour studies, it currently seems to be the least appropriate display option available. This brings the interesting possibility of replicating previous work which used photograph, using 360° panorama or VR formats, depending on the nature of the response to be studied.

Secondly, certain formats present a marked deviation from the physical environment in terms of some psychological responses. More specifically: in the case of the 360° panorama format, some dimensions, especially 'originality' and 'potency' tend to be overestimated; in the case of photograph, some dimensions are underestimated, such as 'affection', 'unity', 'pleasantness' and 'pleasure'. Overestimation in the 360° panorama format may be because the platform-format combination (HMD - 360° panorama) produces a particularly polished experience which guides the user towards valuing the uniqueness of the experience more than their own environment, known as the 'novelty effect' (Bardo et al., 1996). Of special interest are the high scores in the 'arousal' dimension, especially in the VR format. This may be due to the format's stereoscopy (Cho et al., 2014), or by motion sickness which can be provoked by navigation in this format (Reason and Brand, 1975). Conversely, it is worth highlighting the 'dominance' dimension, which presented significantly negative values in all three formats. This factor, which is related to safety or control of the subject in the environment, might have been negatively affected by a technological component, by the use of the HMD system, as well as methodological. The subject sees a displayed stimulus while receiving oral instructions from a researcher who they cannot see, which thus generates a lack of dominance. We must take into account that the received experience is a mixture of the simulated environment and the rest of the stimuli from the space where it is located (Loomis, 1992). On the other hand, in general, we observed a greater sense of presence, the higher the physiological response to the approximation was. This is consistent with certain authors who have indicated that presence is not only the feeling of 'being there' but also requires the users to act as if they were there (Sanchez-Vives and Slater, 2005), in such a way that the higher the users' feeling of presence, the closer their behaviour is to that in the physical environment (Kober et al., 2012).

Finally, with regard to the physiological measurement, two contributions must be highlighted. The first of them is the use of portable and minimally-invasive physiological recording technologies. This devices are increasingly improving: smaller, autonomous, inexpensive, and user-friendly, while remaining highly accurate and reliable (McCann and Bryson, 2009); leading to the current rapid applications in the area of human factors (Axisa et al., 2004). Secondly, it is worth noting the results provided by this physiological measurement tool and its significant correlation with some psychological responses. Importantly, its correlations with the 'pleasure' dimension and the feeling of presence especially stand out. Regarding the former is observable both in the Phasic-EDA and the nHF-HRV data, while the latter nearly reaches a significant level. This is consistent with other studies reporting HR deceleration (Christie and Friedman, 2004; Palomba et al., 2000; Schwartz et al., 1981) in response to visual stimuli aimed at generating contentment, and agrees with studies indicating an increase in the Phasic-EDA in response to amusement (Britton et al., 2006) or a state mixture of joy and pride (van Reekum et al., 2004). Regarding the feeling of presence, it correlates significantly and negatively with the normalised values of the nHF-HRV. Thus, our results coincide with previous studies which found a decrease in nHF-HRV as realism increased (Slater et al., 2009), and may replicate those described by Meehan, Insko, Whitton and Brooks (Meehan et al., 2002) which detected a correlation between an increase in HR and the feeling of presence. However, the results we present here differ from this latter study which found a correlation between EDA and the feeling of presence, albeit with certain limitations. This discrepancy might be due to the stressful nature of the stimulus used in the aforementioned study (a pit). Regardless of this, it is possible that these differences also partly resulted from the use of different systems to evaluate these metrics, and the complexity of defining and measuring the feeling of presence (Lombard and Ditton, 1997). Together, these correlations suggest that it is possible to develop models that can predict these psychological responses via EDA and HRV measurements (Dillon et al., 2002; Lee et al., 2006). Thus, an interdisciplinary research field that integrates neurophysiological bases with design and technology (Parasuraman and Rizzo, 2008) to improve the interface between humans and machines in different application domains is emerging (Liu et al., 2011).

In parallel, some limitations must also be considered, in particular, the restrictions of using a HMD platform and the study of a specific environment. Regarding the former, it was considered relevant homogenize the experience regarding the display system used for the evaluation of the three formats. It is possible that the results might differ if another display system or even another technological device were used. For example, if the 360º panorama had been visualized by means of a screen, it is likely that the previously mentioned 'novelty effect' would have been lost, minimizing the impact in the 'originality' dimension. On the other hand, if the VR experience had been developed in a cave automatic virtual environment (CAVE), it is possible that the observed lack of dominance while using this display would have been reduced, given the fact that the subject has greater control over the physical space around him. In another vein, it should be noted that when comparing the three formats we must consider that the photograph and 360° panorama formats are both photographs of real scenes, while VR is a modelled simulation whose level of realism is lower. Nevertheless, it is possible that at the current rate of progress VR will soon achieve a high level of photorealism (Lovett et al., 2009). On the other hand, it is possible that the obtained results are conditioned by the specific studied environment, so that when altering spatial properties or analysing a different space the results would be modified. There are scenarios that may seem singular in some of the dimensions of the study (for example 'originality'), and they are not adequately captured by a specific display format (for example by means of photograph). In future works, it would be interesting to replicate this study using different display set-ups or environments. Thus, for example, Augmented Reality is becoming increasingly significant and it is foreseeable its greater incorporation into studies analysing behaviour-experience-environment relationship. On the other hand, other neuroscientific methods such as electroencephalographic (EEG) would allow to expand the study of objective responses.

5. Conclusions

We presented a methodology for validating existing simulation-environment display formats (photograph, 360° panorama, and VR) using psychological and physiological human responses. The results suggest that 360° panoramas tend to obtain the best psychological outcome scores while VR scored the best for physiological measurements. In addition, we also found some correlations between psychological and physiological responses and the sense of presence. Specifically, we were able to predict the participants' pleasure experienced using the Phasic-EDA, and the feeling of presence using nHF-HRV. Our methodological contribution lies in the simultaneous measurement of the participants' psychological and physiological responses in such a way that the validation addresses the different aspects involved in the overall experience. Our results may also be of interest to researchers looking forward to take advantage of the visualisation technologies currently available to replicate the experience of physical environments in an investigative context.

05
Artículo 3
Paper 3

"Digital space: Comparative evaluation of the latest architectural techniques"

Este artículo fue publicado en la revista "EGA Revista de Expresión Gráfica Arquitectónica" (ISSN 1133-6137). Es una revista internacional, revisada por pares (siguiendo una double-blind review), sobre aspectos variados de la expresión gráfica en arquitectura. La revista "EGA Revista de Expresión Gráfica Arquitectónica" es referente en áreas de conocimiento como la arquitectura o las artes visuales; estando indexada en SJR (Q3 – 0.107 en 2017, año de su publicación; categorías "architecture" y "visual arts and performing arts"). Según *Google Scholar*, hasta la fecha este artículo ha sido citado 11 veces.

Higuera-Trujillo, J. L., López-Tarruella, J., Llinares, C., & Iñarra, S. (2017).
Digital space: Comparative evaluation of the latest architectural techniques.
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This paper was published in the journal "EGA Revista de Expresión Gráfica Arquitectónica" (ISSN 1133-6137). It is an international, peer-reviewed journal (following a double-blind review), on various aspects of graphic expression in architecture. The journal "EGA Revista de Expresión Gráfica Arquitectónica" is a reference in areas of knowledge such as architecture or visual arts; being indexed in SJR (Q3 - 0.107 in 2017, year of publication; categories "architecture" and "visual arts and performing arts"). According to Google Scholar, this paper has been cited 11 times to date.

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Abstract

The great technological evolution of architectural rendering resources over the last few decades has opened up a new range of possibilities to visualise the non-built space. The spatial immersion systems, developed by the videogame industry, have entered in the sceptical area of architectural rendering, offering a series of undeniable advantages including enhancing the understanding of spaces to inexpert people. In order to study the benefits of these new virtual tools, an experimental study was carried out so as to compare the user response to technological and graphic supports. With a simple of 84 individuals, the obtained data reveal significant differences in the space perception depending on the format and support used to their representation. The results of this study allow us to reflect on new means of architectural rendering in the professional and teaching field.

1. Introduction

Owing to their inherent spatial dependence (Bollnow, 1969), human beings have always needed to represent their surroundings (Rohrmann & Bishop, 2002) through environmental simulations as accurate as possible according to their purpose (de Kort et al., 2003). In the case of architecture, they come to play a pivotal role in its language (Sainz, 2005), either professional or pedagogical (Figure 5.1).

Figure 5.1. Immersive Virtual Reality. Proyect: Carratalá arquitectos. Picture: bgstudio.

In order to generate architectural simulations, there are a multitude of available tools which have been included and recycled to the extent that technology has enabled it. From traditional drawings and scale models to photography, video and montages. Nowadays, constant innovations in computing applied to simulation by tridimensional models are transforming "Virtual Reality", quondam unapproachable technology, into a common tool which, according to some authors (Ackerman, 2002), will imply a revolution comparable to that one which meant the paper introduction (Figure 5.2)

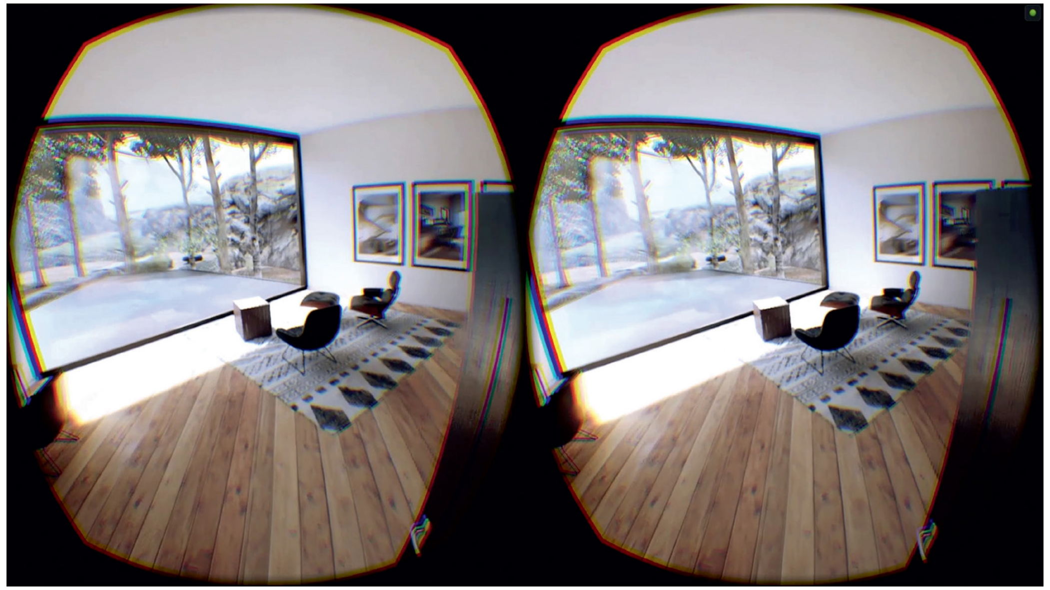

Figure 5.2. Stereoscopic Immersive Visualization. Proyect: "River House. An Exploration of Using Virtual Reality to present an Architectural Project". Picture: courtesy of Thomas Walker.

Virtual Reality offers the possibility of creating architectural renderings which generate the sensation of "being there" (Steuer, 1992). In order to do it, presentation devices are jointly used such as monitors or Head-Mounted-Display ("Virtual-Reality" headsets), and interaction devices such as keyboards and joysticks (de Kort et al., 2003). In spite of the fact that its capability to generate realistic simulations is increasing (Rohrmann & Bishop, 2002), Virtual Reality still has some limitations (for a review see: de Kort et al. 2003). Nevertheless, although a simulation will never equal to reality, the progress which it constitutes in language (Pietsch, 2000) and the architectural fact are undeniable.

Technology and its applications are immerse in profound changes, being considered as a paradigm shift (de Kort et al., 2003). On the one hand, we find the rapid development of new formats and supports and, on the other hand, the increase in their use and standardisation in the professional sector (Bishop & Rohr Mann, 2003). As a consequence, despite lots of studies having been conducted on the simulation of surroundings, the previous investigations are now insufficient (Arthur E. Stamps, 1990). Thus, it is crucial to update them in order to include technological advances.

One of the main issues in the simulation field is the study of its function depending on the context in which it is used (Kalawsky, 2000). In the same manner as a drawing with a low level of detail may contain the most valuable information, an environmental representation may be useful without being particularly realistic. In this sense, it is important to specify that environmental simulation has two main functions: to study human perception and to represent design aspects. The first one has found affinity in environmental psychology and the second one has found it in design in general and to architecture in particular. Therefore, it is an essential tool whose utility must be studied appropriately.

The study of the utility of simulations is linked to the concept of 'credibility' (Buller & Burgoon, 1996). Ever since the work of Appleyard (1977) determined the aspects involved in the credibility of representations, these have been redefined (S. Sheppard, 1989) and condensed (Pietsch, 2000; Radford et al., 1997): 'precision', accuracy which permits to acquire knowledge similar to unlimited observation; 'realism', generation of an experience similar to the real one (Hall, 1990), and 'abstraction', related to the level of detail (Bates-Brkljac, 2009). Being thoroughly studied in traditional representations and briefly in architectural renderings created with new means such as renders (Otxotorena 2007) or Virtual Reality (Bates-Brkljac, 2009), it constitutes a transversal approximation which is acceptable to study and to compare the utility of a wide range of available formats-supports in architectural graphic expression.

However, despite technical information is comprehensive, we do not find many studies regarding the detailed and combined effect of new formats and supports on architectural simulation, not even their comparison with more traditional ones. And, when we find them, the rate with which technology evolves leaves them outdated. Are new means an advantage in the validity of a representation or a design aid? Which are the most appropriate? Without an updated assessment, the choice falls squarely on the intuition of a professional or a teacher, with the limitations which this implies.

Thus, our aim is to study the adequacy of the main formats and supports currently used in architecture. Following trends in research in the technological market and in architectural production, "Traditional Photography", "Panoramic Photography" and "Virtual Reality" were considered as formats, and "Monitor" and "Head-Mounted-Display" as supports. During the study, architectural renderings of a same environment created by a combination of the aforementioned formats and supports were assessed with differential semantics. In order to do it rigorously according to the theory of architectural graphic expression, they were equalled with regard to "use", "display model" and "graphic technique" (Sierra, 1997), thereby making a useful comparison for researchers, teachers and architecture professionals.

2. Materials and Methods

In order to have a space with controlled laboratory conditions to carry out the experiment, the space to visualise was a room themed as a drinks selling zone located in the Laboratory of Immsersive Neurotechnologies (LENI) at Universidad Politécnica de Valencia.

2.1 Formats

The following formats were selected (Figure 5.3):

- Photograph taken with GoPro Hero3+-Silver camera. Taking into account the inherent limitation of this format to capture the entire environment, the most representative point of view was selected (Hetherington et al., 1993)(2.
- 360°x180° panoramic photograph generated on the basis of 6 photographs.
- Stereoscopic and interactive Virtual Environment viewable in first person.

Figure 5.3. Traditional Photograph (above) and Virtual Environment (below) of the evaluated space.

2.2. Supports

The following visualization supports were selected:

- Laptop with a 15.6-inch screen and 1280x720 resolution.
- Head-Mounted-Display Samsung Gear VR with stereoscopic screen of 1280x1440 resolution per eye, head position tracking and navigation through a wireless joystick.

The evaluated combinations were those ones which are included in Figure 5.4.

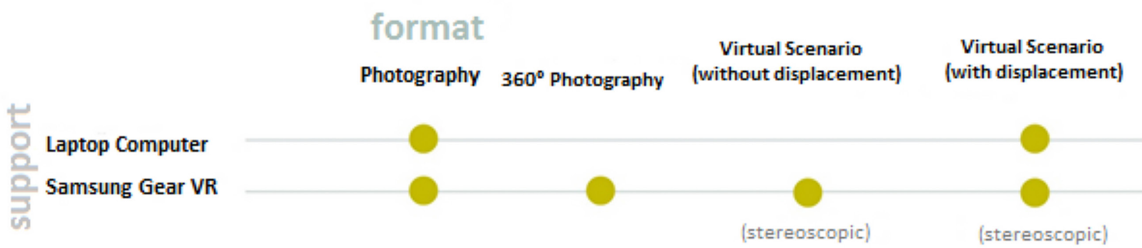

Figure 5.4. Combinations of evaluated formats and supports.

2.3. Questionnaire

To collect the user response, a questionnaire of space assessment was designed using 7-point Likert scales, being 1 the minimum score and 7 the maximum score for the concepts:

- Abstraction
- Precision.
- Realism.
- "It may orient me easily".
- "It would help me make decisions on interior design".

2.4. Sample

The total studied sample was 84 individuals. Figure 5.5 shows the sample structure by age and gender. The sample size was calculated considering a confidence level of 95 per cent, a variance of 2.5 (according to similar studies) and an error margin of 1, resulting in a minimum N of 10 individuals per stimulus.

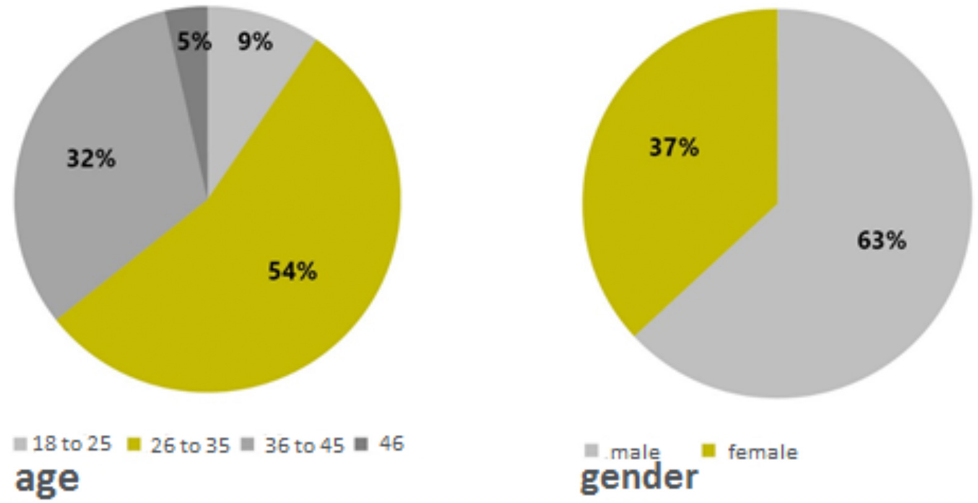

Figure 5.5. Demographic structure of the studied sample.

2.5. Development of the experience

The experimental phase was conducted in the laboratory, in the same room for all experiences (Figure 5.6). At the beginning of each session, the subject received information on the experiment and the consent form. Then, the instructions were explained to the subject and, so as to start the experiment under the same circumstances, they were sitting in a comfortable position, listening to a relaxing audio with their eyes closed for two minutes and next, a randomized stimulus for ten minutes and the questionnaire was given to each one.

Figure 5.6. Photographs taken during the experimentation.

The shown stimuli were randomized as indicated in Table 5.1.

Table 5.1. Visualisation frequency of different combinations of formats and supports.

	Stimuli	Frequency
1	Photography / Laptop Computer	14
2	Photography / Samsung Gear VR	11
3	360 Photography / Samsung Gear VR	10
4	Virtual Environment (without movement) / Samsung Gear VR	11
5	Virtual Environment (with movement) / Samsung Gear VR	13
6	Virtual Environment (with movement) / Laptop Computer	15

2.6. Data processing

Collected data were statistically processed by the statistical software SPSS 22.0. Firstly, a descriptive analysis was carried out to identify tendencies in the results.

Then, stimuli were grouped. On the one hand, into three formats depending on the freedom of vision permitted: image with static point of view (stimuli 1 and 2), image with free viewing angle (stimuli 3 y 4) y Virtual Environment with free movement (stimuli 5 and 6). On the other hand, into two display supports: laptop (stimuli 1 and 6) and Head-Mounted-Display (stimuli 2, 4 and 5).

Subsequently, statistically significant correlations were sought among concepts, formats and supports. The non-parametric Spearman´s Rho correlation coefficient was used since the samples did not follow a normal distribution in the Shapiro–Wilk Test.

Finally, statistically significant differences were sought between formats and supports according to the assessed concepts. The non-parametric tests of Kruskal-Wallis (formats) and of Mann-Withney U (supports) were used, defining a 5% significance level and a 95% confidence interval.

3. Results

The standardized z-scores show a clear division between the photographs and the Virtual Environments in relation to the abstraction, precision, and realism concepts. Equally, differences between the traditional photography and the formats are appreciated, with a higher degree of immersion in relation to the easiness of orientation and design aid concepts (Table 5.2). The pooled means by format and support emphasize these results.

Table 5.2. Pooled means of the concepts segmented by stimulus, formats, and supports.

		Abstraction	Precision	Realism	Orientation	Design aid
Stimulus	Photography / Laptop Computer	-.360	.444	.345	-.446	-.868
	Photography / Samsung Gear VR	-.112	.087	.345	-.404	-.488
	360 Photography / Samsung Gear VR	-.223	.475	.345	.470	.577
	Virtual Env. (without movement) / Samsung Gear VR	.137	-.307	.204	.012	.642
	Virtual Env. (with movement) / Samsung Gear VR	.218	-.454	-.606	.012	.331
	Virtual Env. (with movement) / Laptop Computer	.278	-.176	-.428	.379	.025
Format	Static image	-.251	.287	.345	-.427	-.700
	360º image	-.035	.065	.271	.230	.611
	Virtual Environment	.250	-.305	-.511	.209	.167
Supp	Laptop Computer	-.030	.123	-.055	-.019	-.406
	VR Headsets	.089	-.238	-.053	-.118	.171

The Spearman test shows a series of statistically significant relationships between concepts, formats and supports (Table 5.3). Figure 5.7 schematize these relationships.

- Regarding the concepts, abstraction, precision and realism show strong links between them. Precision and realism are linked with the easiness of orientation. Finally, the easiness of orientation is directly linked with the design decisions aid.
- Regarding the formats, the 360º image and the traditional image are related respectively positively and negatively with the ability of design aid.
- Regarding the supports, the Head-Mounted Display and the traditional screen are related respectively positively and negatively with the ability of design aid.

Table 5.3. Significant correlations between concepts, formats, and supports.

			Abstraction	Precision	Realism	Orientation	Design aid
Concept	Abstraction	Coeff.		-.427**	-.262*	-.176	.007
		Sig.		.000	.024	.133	.950
	Precision	Coeff.	-.427**		.493**	.425**	.167
		Sig.	.000		.000	.000	.156
	Realism	Coeff.	-.262*	.493**		.305**	.191
		Sig.	.024	.000		.008	.103
	Orientation	Coeff.	-.176	.425**	.305**		.418**
		Sig.	.133	.000	.008		.000
	Design aid	Coeff.	.007	.167	.191	.418**	
		Sig.	.950	.156	.103	.000	
Format	Static image	Coeff.	-.195	.211	.242*	-.248*	-.471**
		Sig.	.095	.072	.038	.033	.000
	360º image	Coeff.	.028	.056	.159	.137	.400**
		Sig.	.816	.616	.176	.243	.000
	Virtual Environment	Coeff.	.165	-.260*	-.383**	.115	.088
		Sig.	.160	.025	.001	.331	.457
Support	Laptop Computer	Coeff.	-.124	.204	-.009	.068	-.323**
		Sig.	.330	.106	.945	.594	.009
	VR Headsets	Coeff.	.124	-.204	.009	-.068	.323**
		Sig.	.330	.106	.945	.594	.009

Finally, non-parametric tests show the statistically significant differences in relation to the design aid concept.

- Regarding the formats, traditional photography shows a worse score (level of significance of 0.000) than its two more immersive competitors.
- Regarding the supports, there are also differences (level of significance of 0.01), being higher the score of the Head-Mounted Display.

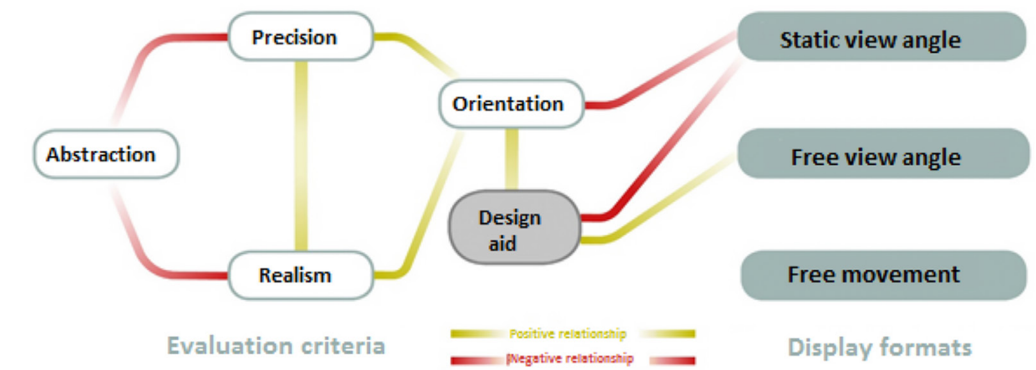

Figure 5.7. Relations scheme between formats and concepts.

4. Conclusions

Firstly, it has been proved that the slate of aspects 'precision-abstraction-realism' are closely interrelated, as could be foreseen given that they are different components of the same underlying concept. Thereon the present work also involves an emerging contribution to the implementation of this theoretical framework on new formats and supports. Thus, despite in this respect an ad hoc research should be carried out, it can be advanced that in the field of architecture it is valid for the study of the credibility of new ways of graphic representation and their comparison to the traditional ones.

Secondly, the new formats and supports for the representation of spaces produce higher scores as 'design aid' tools. Regarding formats, panoramic image presents the highest scores in its photorealistic version (360o x 180o) as well as in its virtual one (stereoscopic Virtual Environment without movement), followed by the Virtual Environments with free movement. Regarding the supports, the visualization by means of Head-Mounted Display shows higher scores for photography as well as for Virtual Environments.

The classification of the different formats and supports according the concept 'design aid' shown in Figure 5.8, allows us to reflect on the direction that these new visual tools must take in the teaching and professional field. Understanding design as the creative process in which the architectural proposal is formalized, this experimental study shows us that the current wide range of digital tools can be extremely useful for the architect during each of the phases of the project, from the analysis to the visual communication.

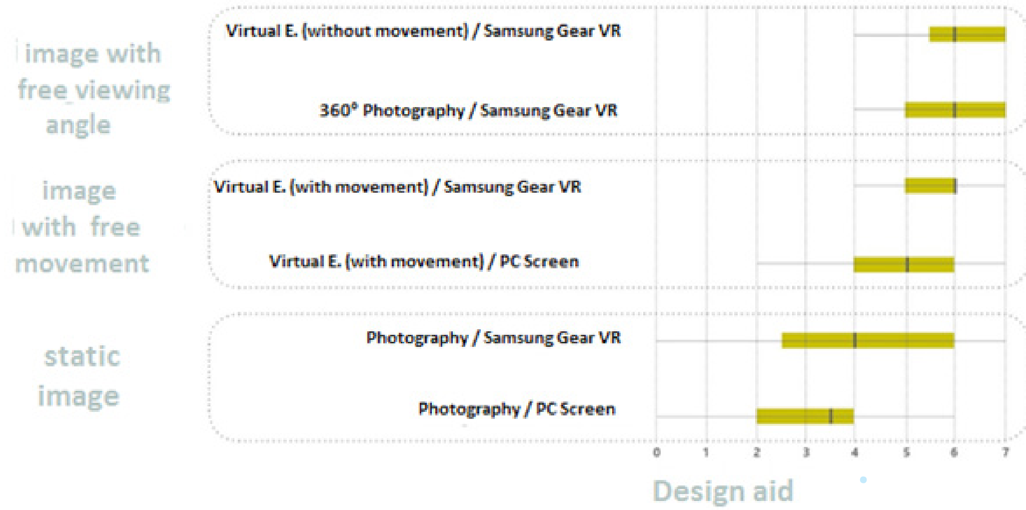

Figure 5.8. Box diagrams of the 'design aid'.

06.

Artículo 4

Paper 4

"User evaluation of neonatology ward design. An application of focus group and semantic differential".

Este artículo fue publicado en la revista "HERD: Health Environments Research & Design Journal" (ISSN 1937-5867). Es una revista internacional, revisada por pares (siguiendo una double-blind review), centrada en mejorar el diseño hospitalario. En este sentido, es la única revista dedicada a publicar artículos basados en evidencias sobre el diseño de estos entornos. Está dirigida a un público variado; entre ellos: representantes de la sanidad (enfermeros, médicos, psicólogos, neurocientíficos) y del diseño (arquitectos, diseñadores de interiores, y diseñadores gráficos). Así, la revista "HERD: Health Environments Research & Design Journal" es referente en áreas de conocimiento como la salud púbica; estando indexada en SJR (Q2 – 0.449 en 2017, año de su publicación; categorías "critical care and intensive care medicine" y "public health, environmental and occupational health") y JCR (Q3 - 1.387 en 2017; categoría "public, environmental & occupational health" - 93/157). Según *Google Scholar*, hasta la fecha este artículo ha sido citado 14 veces.

Higuera-Trujillo, J. L., Montañana, A. & Llinares, C. (2017). User evaluation of neonatology ward design: An application of focus group and semantic differential. *HERD: Health Environments Research & Design Journal*, *10*(2), 23-48.
DOI: https://doi.org/10.1177/1937586716641275

This paper was published in the journal "HERD: Health Environments Research & Design Journal" (ISSN 1937-5867). It is an international, peer-reviewed journal (following a double-blind review), focused on improving hospital design. As such, it is the only journal dedicated to publishing evidence-based papers on the design of these environments. It is targeted at a wide range of audiences, including representatives of the healthcare (nurses, doctors, psychologists, neuroscientists) and design (architects, interior designers, and graphic designers). Thus, the journal "HERD: Health Environments Research & Design Journal" is a reference in areas of knowledge such as public health; being indexed in SJR (Q2 - 0.449 in 2017, year of publication; categories "critical care and intensive care medicine" and "public health, environmental and occupational health") and JCR (Q3 - 1.387 in 2017; category "public, environmental & occupational health" - 93/157). According to Google Scholar, this paper has been cited 14 times to date.

Higuera-Trujillo, J. L., Montañana, A. & Llinares, C. (2017). User evaluation of neonatology ward design: An application of focus group and semantic differential. *HERD: Health Environments Research & Design Journal*, *10*(2), 23-48.
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Abstract

Objective: The object of this paper is to identify the set of affective and emotional factors behind users' assessments of a space in a Neonatology Unit, and to propose design guidelines based on these. Background: The importance of the Neonatology Service and the variety of users place great demands on the space at all levels. Despite the repercussions, the emotional aspects of the environment have received less attention. Methods: To avoid incurring limitations in the user mental-scheme, this study uses two complementarily methodologies: Focus Group and Semantic Differential. The (qualitative) Focus Group methodology provides exploratory information and concepts. The (quantitative) Semantic Differential methodology then uses these concepts to extract the conceptual structures that users employ in their assessment of the space. Of the total 175 subjects, 31 took part in focus groups and 144 in Semantic Differential. Results: 5 independent concepts were identified: privacy, functionality and professional nature, spaciousness, lighting, and cleanliness. In relation to the importance with the positive overall assessment of the space, the perception of privacy and sensations of dominance and pleasure are fundamental. 6 relevant design aspects were also identificated: provide spacious surroundings; facilitate sufficient separation between the different posts or cots; use different colours from those usually found in healthcare centres, as some aversion was found to white and especially green; design areas with childhood themes; use warm artificial light; and choose user-friendly equipment. Conclusions: Results provide design recommendations of interest and show the possibilities offered by combining both systems to analyse user response.

1. Introduction

Neonatology is a subspeciality of paediatrics that focuses on the neonatal period (Chen, Oetomo, & Feijs, 2010), understood as the period extending up to 46 weeks' postmenstrual age. This period is particularly important because of its impact on the way children develop and their subsequent quality of life as adults (Stevenson & Cooke, 1998), and doubly so in the current situation of longer life expectancy and greater demands on health services (Guerra de Hoyos & de Anca Contreras, 2007). The neonatology service is provided in the neonatology unit. The unit provides assistance with birthing and reanimation. It covers healthy newborns and neonatal patients (Rite Gracia et al., 2013), who (especially premature babies) are particularly dependent and vulnerable to the background which supports their physiological and neurobehavioural organisation (Blackburn, 1998). Users of the unit are health staff, neonatal patients and their parents and other family relations. The importance of the service and the wide variety of users, each with their functional and emotional needs, place great demands on the space at all levels.

Many of these demands, however, are not always met. For example, some studies show that the stress inherent in this type of scenario can cause long-term damage to health if it is moderate and continuous, as in the case of the hospital staff (Cohen, Tyrrell, & Smith, 1991; Fliege et al., 2005); it has negative consequences for recovery, of chronically ill patients, anticipating painful processes (Ward, Brinkman, Slifer, & Paranjape, 2010), and of temporary patients separated from their parents in an unfamiliar environment (Jessee, Wilson, & Morgan, 2000; Yip, Middleton, Cyna, & Carlyle, 2009). Furthermore, numerous studies highlight problems stemming from environmental factors, for example, excessive noise (Jonckheer, Robert, Aubry, & De Brouwer, 2004), inadequate lighting (Blackburn, 1996; J. Robinson, Moseley, & Fielder, 1990) and insufficient hygiene (Dicko-Traore et al., 2011). Excessive noise has a negative impact on newborn behaviour, altering sleep and causing agitation and crying (Blackburn & Vandenberg, 1993; K. A. Thomas, 1995; Zahr & de Traversay, 1995), and at physiological level, it increases intracraneal pressure and reduces oxygenation (Long, Lucey, & Philip, 1980). Inadequate lighting negatively affects growth and development (Blackburn, 1998); and lack of hygiene causes numerous nosocomial infections, increasing morbidity and mortability and costs (Pittet, Allegranzi, & Widmer, 2008). It therefore seems clear that neonatal departments can be improved by designing the areas to fulfil users' physical and utilitarian needs (Rite Gracia et al., 2013). It is also essential and possible for that design to support their emotional needs as well (Leather et al., 2003). These issues must therefore be resolved in order to deliver quality healthcare (Lawson, 2010).

With the progress in medicine and applied technologies, technical solutions have provided substantial improvements to satisfy users' physical and medical needs. Some of these improvements include technical standards and protocols that regulate space-related aspects from a medical perspective (e.g., Rite Gracia et al., 2013; White, Smith, & Shepley, 2013; for a review see García del Río et al., 2007). In addition, there have been numerous design-led efforts to develop patient-focused health care models (Schattner, Bronstein, & Jellin, 2006). Patients record their experiences (Britto et al., 2004; Grol et al., 2000) or how they use the space (Battisto & Allison, 2008), so this information can be used to design health care services (Christenson et al., 2010; Coad & Coad, 2008; Moules, 2009). This process can also adopt an iterative design and correction procedure to refine the design and reduce costs by avoiding changes at advanced stages of execution (Nielsen, 1993). It has been used in particular to address the utilitarian needs of adult (Dijkstra, Pieterse, & Pruyn, 2006), and adolescent patients, as well as children and newborns (Boswell, Finlay, Jones, & Hill, 2000; Eisen, Ulrich, Shepley, Varni, & Sherman, 2008). Focusing on paediatric patients, this type of research provides recommendations like providing parents with overnight stay facilities (bedrooms or suitable chairs) so they can become more involved in the treatment (Vavili, 2000); increasing the sensation of control over the health care process to reduce the family's stress (Acton et al., 1997); satisfying the need for privacy in adolescence (Wolfe & Laufer, 1974) with measures for increasing children's perceived intimacy in bathrooms and permitting access to audiovisual and online content (Blumberg & Devlin, 2006). The use of technical and utilitarian solutions to resolve functional aspects is immensely important and numerous contributions have helped to improve healthcare services.

However, less attention has been paid to the more purely emotional aspects of the environment. Studies show that physical and psycho-social aspects of the environment interact on the sensation of wellbeing (Evans, Johansson, & Carrere, 1994), and may alleviate or worsen existing psychological stress (Leather et al., 2003). This relationship is paramount in health care spaces, where it has been found that stress associated with the stay stems not only from the illness itself (Cohen & Lazarus, 1979), but also from adaptation to an unfamiliar environment (Shumaker & Reizenstein, 1982). Thus a project that takes into account the patient's need for comfort through its design characteristics can mitigate the sensation of stress during a hospital visit (Zimring, Carpman, & Michelson, 1987), and inappropriate design can contribute to anxiety (Ortega-Andeane, 1991); especially in the case of children who are particularly sensitive to the situation they find themselves in when in hospital (Blumberg & Devlin, 2006).

Increased interest in the emotional dimension of hospitals in recent years (Blumberg & Devlin, 2006) is clear from the portrait of the way these environments have evolved (e.g., Devlin & Arneill, 2003). Although such studies are largely based on self-reports, other more in-depth approaches have been gradually incorporated (Blumberg & Devlin, 2006), such as Evidence-Based-Design (Ulrich, Quan, Zimring, Joseph, & Choudhary, 2004). This approach links architectural design parameters to user responses, and has been profusely applied in the area of hospitals (Leather et al., 2003) since Roger Ulrich presented the influence of surroundings on patient wellbeing and recovery. Findings from studies that focus on the emotional experience include, for example, a relationship between number of windows and wellbeing (Verderber, 1982); scenes visible from rooms and anxiety in open-heart surgery patients; and the design of rooms, lobbies, operating theatres and corridors from the perspective of adolescents' preferences (Blumberg & Devlin, 2006; Ullán et al., 2012). Complete fulfilment of the needs of different patient profiles is therefore not simply a question of medical and utilitarian factors. Emotional factors must also be directly addressed, with particular attention to issues like stress (Evans, Crooks, & Kingsbury, 2009).

A common feature of these studies is that they usually evaluate patients' impressions through questionnaires or multiple choice tests; experts decide on the relevant attributes of the space and relate them to an analytical variable. This approach, however, means that the mental scheme of the non-expert may be distorted or not taken into account. This risk exists even when dimensions already defined from different stimuli or other geographical and time contexts are used. Although the results of these works are undoubtedly plausible and their approaches present certain specific benefits, studies using variables that reflect the affective and emotional mental structure of specific users are also needed.

This study aims to identify the set of affective and emotional factors behind users' assessment of the space in a neonatology unit and to propose design guidelines based on these findings. This goal is broken down into four sequential objectives: (a) identify, from the qualitative perspective, users' needs in neonatal wards, in order to find the concepts for the next sub-objective; (b) identify the affective structure related to the description of these wards; (c) identify the influence at quantitative level, of the affective and emotional structure on the assessment of the space; and (d) identify the relevant design parameters in users' assessments. Kansei methodology was used to achieve these objectives.

Kansei engineering was developed in the 1970s at the Kure Institute of Technology (Hiroshima, Japan). It is a method for developing consumer-friendly products that translates emotions, concerns and needs into design parameters (Nagamachi, 1995). Two stages are used to achieve this objective. The first stage uses the semantic differential method to identify and quantify users' perceptions of a product or stimulus in their own language; and in the second stage, the relationships between subjective responses and the design characteristics are determined qualitatively (Nagamachi, 1989). It has been applied to different sectors, including the car industry (Jindo & Hirasago, 1997), and acoustics (Kang & Zhang, 2010); and has proven to be an advantageous technique for the design of user-friendly products.

The semantic differential procedure, developed by Osgood, Suci, & Tannenbaum (1957), assumes an underlying structure in the semantic evaluation of products or stimuli. This structure can be found by evaluating a set of stimuli (which must have general characteristics of the type being studied) using adjectives and expressions defined by users on a Likert scale. If factor analysis of the valuations shows that a limited number of factors (called semantic axes) is sufficient to differentiate between the meanings of the entire set of concepts (called semantic space) then these axes define the semantic basis for expressing any product of the type. It is currently the most powerful technique available for measuring the affective meaning of concepts (Ishihara, Ishihara, Nagamachi, & Matsubara, 1997).

Evaluation of the set of stimuli by semantic differential requires identification of the concepts that represent the specific needs of the users being studied. To that end, the qualitative research technique of a focus group was used, consisting in carefully planned and directed group discussions to obtain information on the subject of study through participants' experiences and opinions (Krueger & Casey, 2000). This group interaction is the main difference with other qualitative techniques and although the technique has some drawbacks (Reed & Payton, 1997), it does offer advantages in certain situations. For example, it can be used to inspect the nature of social dynamics (Kamberelis & Dimitriadis, 2005) and thus improve their portrayal (Morgan & Krueger, 1998). As a joint effort it helps to generate new ideas (Krueger & Casey, 2000) and recall aspects that would be difficult to achieve with individual interviews (Kamberelis & Dimitriadis, 2005). Also, the interviewer does not have such an important role as in individual interviews (Madriz, 2000), making the process less intimidating (Morgan, 1997), creating a familiar atmosphere (Steward & Shamdasani, 1994) that encourages the expression of points of view. It is particularly effective for examining the relationship between user and product (Morgan & Krueger, 1998) when, as in our case, there is limited literature (Hsieh & Shannon, 2005); and the technique has demonstrated its validity for evaluating attitudes and experiences (Kitzinger, 1996) in order to improve design, for example, operating theatres (Watkins et al., 2011), waiting rooms for children (Biddiss, McPherson, Shea, & McKeever, 2013) and toilets (Fink et al., 2010). For these reasons the technique was considered ideal for an initial diagnostic of the needs of the service being studied and to collect the concepts used to subsequently identify the affective structure through semantic differential.

The combination of semantic differential and focus group permits identification of user needs at different levels. Firstly, the focus group qualitatively studies users' opinions and attitudes and secondly, semantic differential quantitatively models the observers' mental view of this service which can then be related to their attitude towards the service and even its design parameters.

Despite the advantages of Kansei Engineering, it is not widely used in architecture. Some studies have focused on specific aspects of architecture such as the design of doors (Matsubara & Nagamachi, 1997a) and kitchens (Matsubara & Nagamachi, 1997b), but there are very few studies on a broader truly architectural or urban scale. Such studies include applications to the design of facades (Sendai, 2011), dwellings (Enomoto, Nagamachi, Nomura, & Sawada, 1993; Llinares & Page, 2007; Nagamachi, 1998), urban environments (Kinoshita, Cooper, Hoshino, & Kamei, 2006; Llinares & Page, 2008), and the identification of differences of perception between architects and non-architects (Llinares, Montañana, & Navarro, 2011; Montañana, Llinares, & Navarro, 2013); although scanty, these studies show that the method is valid for determining design parameters with a positive influence on user emotions towards architecture and urban surroundings. However, to date, Kansei Engineering has not been applied to health care spaces or neonatal wards in particular.

2. Materials and Methods

The methodology is structured in two stages based on two field studies (Figure 6.1).

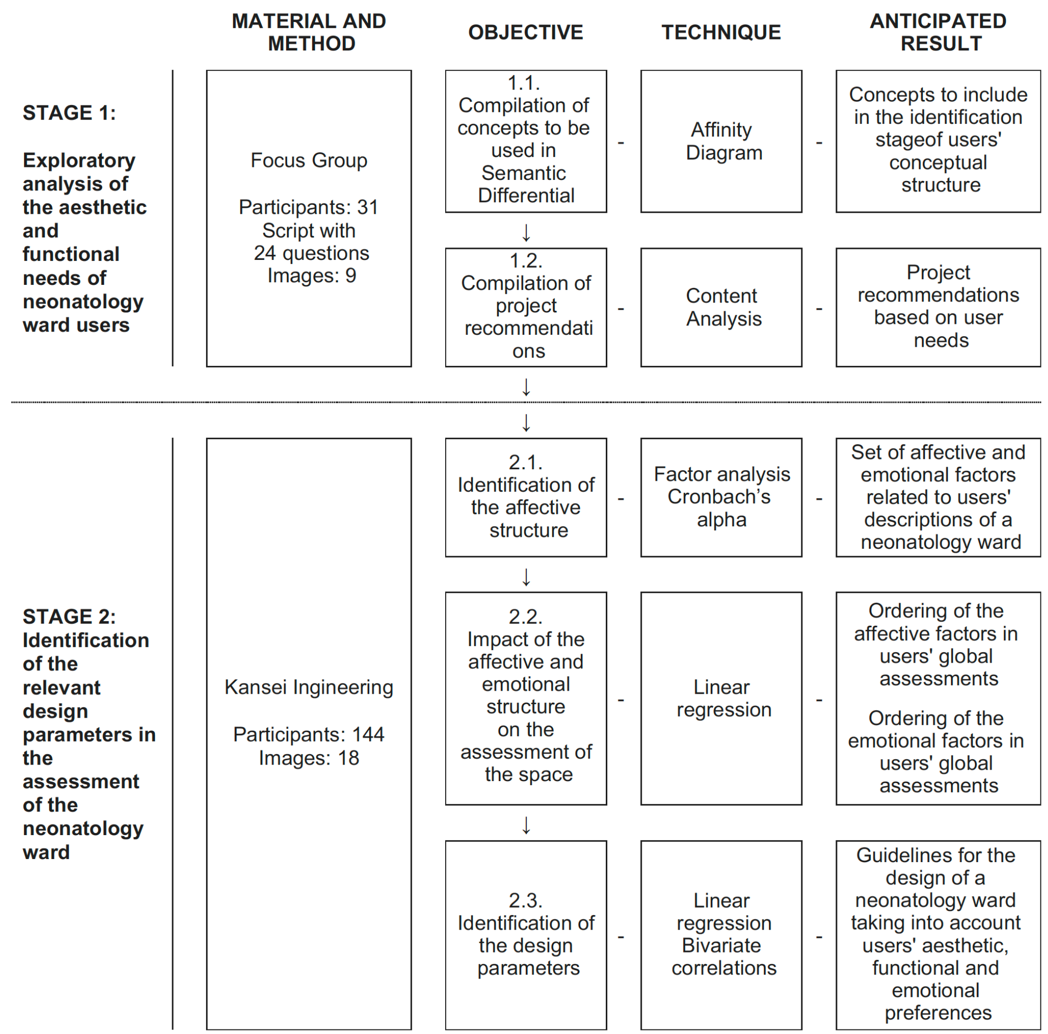


Figure 6.1. Methodology's structure.

2.1. Stage 1. Exploratory analysis of the aesthetic and functional needs of neonatology ward users

Before starting the first stage, approval and consent were obtained from the Institutional Review Board. Information was provided on the specific objectives within the complete research context, detailing the methodology and structure used to achieve them.

The objective at this stage was to extract recommendations for the project and gather the concepts to be used in semantic differential, through focus group sessions with the main profiles of users involved in the service: doctors, nurses and parents. Two sessions were carried out with each profile, to give a total of six. All the sessions and the pre-analyses were carried out at a metropolitan hospital between January and April 2014.

2.1.1. Recruiting participants, forming and convening the groups

The coordinators of the neonatology service and the research team recruited the participants. They did so using the hospital database of users and professionals, choosing those who could be most useful for the study objective in the focus group environment (Curtis & Redmond, 2007; Morse, 1991). General inclusion criteria were that participants had to be of legal age and participate in group contexts. Specific user profile criteria were: (a) professionals (doctor and nurses) with a minimum experience of 10 years in neonatology services and five in the hospital being studied, and (b) parents who were or had been users of the neonatology service within six months from the time of the search. In addition, there could be no more than one member from the same family unit to avoid redundant information, and there had to be the same number of participants from each gender to avoid gender distortion. Finally, 32 participants were chosen, but only 31 (eight doctors, eight nurses and 16 parents) agreed to participate (Table 6.1).

Table 6.1. Participant characteristics.

Participant	Transcription code	Session	Gender	Age	Years of experience (only professional profiles)
Doctor 1	D-1-1	1	Female	39	15
Doctor 2	D-1-2	1	Female	41	16
Doctor 3	D-1-3	1	Male	46	19
Doctor 4	D-1-4	1	Male	40	15
Doctor 5	D-2-1	2	Female	57	31
Doctor 6	D-2-2	2	Male	56	27
Doctor 7	D-2-3	2	Female	58	33
Doctor 8	D-2-4	2	Male	52	25
Nurse 1	N-1-1	1	Female	34	11
Nurse 2	N-1-2	1	Female	36	13
Nurse 3	N-1-3	1	Male	31	10
Nurse 4	N-1-4	1	Male	37	16
Nurse 5	N-2-1	2	Male	58	36
Nurse 6	N-2-2	2	Male	51	30
Nurse 7	N-2-3	2	Female	55	33
Nurse 8	N-2-4	2	Female	51	28
Parent 1	P-1-1	1	Male	31	-
Parent 2	P-1-2	1	Male	36	-
Parent 3	P-1-3	1	Male	45	-
Parent 4	P-1-4	1	Male	36	-
Parent 5	P-1-5	1	Male	33	-
Parent 6	P-1-6	1	Male	38	-
Parent 7	P-1-7	1	Male	43	-
Parent 8	P-2-1	2	Female	41	-
Parent 9	P-2-2	2	Female	34	-
Parent 10	P-2-3	2	Female	37	-
Parent 11	P-2-4	2	Female	39	-
Parent 12	P-2-5	2	Female	27	-
Parent 13	P-2-6	2	Female	43	-
Parent 14	P-2-7	2	Female	32	-
Parent 15	P-2-8	2	Female	33	-

Participants were grouped according to the following guidelines in order to facilitate the focus group. The first grouping was according to the user profile in the neonatology service (doctors, nurses and parents). Health professionals were distinguished according to rank or experience in the service, attempting to avoid participants whose position of much greater leadership might intimidate other participants in the group (Krueger & Casey, 2000), maintaining the same number of participants of each gender. The parent profile was separated by gender, because many of the mothers' experiences may be retracted in a unisex environment. And finally, it was ensured that each group had between four to 12 participants (Greenbaum, 1988; Kitzinger, 1995). According to these, two groups per user profile (6 groups in total) were formed with four, seven or eight participants in each (Table 6.2).

Table 6.2. Group characteristics.

User group	Session (Profile-Number)	Participants	Average years of experience (only professional profiles)
Doctor	D-1	2 men and 2 women	16.25 years; σ = 1.64
Doctor	D-2	2 men and 2 women	28.5 years; σ = 3.84
Nurse	N-1	2 men and 2 women	12.5 years; σ = 2.29
Nurse	N-2	2 men and 2 women	31.75 years; σ = 3.03
Parent	P-1	7 men	-
Parent	P-2	8 women	-

All the groups were led by the same two interviewers following the recommendations by (Krueger & Casey, 2000): one of the members had focus group experience and intervened as moderator, and the other as assistant. The focus group sessions took place in a meeting room provided by the hospital and located within the studied neonatology service. The place was chosen because it was not a threatening context and also offered the opportunity to recall experiences (Godden & Baddeley, 1975) during use of the service.

2.1.2. Structure and preparation

The Focus Group consisted of two sessions per user profile (doctors, nurses and parents) to give a total of 6. All the sessions were structured in four stages. (1) Stage 1: free discussion, dealing with general issues concerning daily use of the service. (2) Stage 2: free discussion, focused on more specific spatial and emotional aspects. In this stage post-its were distributed to stimulate the discussion (Peterson & Barron, 2007). (3) Stage 3: guided discussion, in which nine colour photographs of neonatology spaces, chosen in an attempt to present sufficiently differentiated design aspects, were assessed. (4) Stage 4: guided discussion in which three of the previous pictures chosen at random according to a list of attributes were evaluated. The questionnaire was a list of 33 attributes (chosen from a compilation based on the literature on neonatology ward projects and professional journals) to evaluate on a Likert-type scale ranging from -2 (totally disagree) to 2 (totally agree). The participants had to complete it individually and then present their difficulties.

Before holding the focus groups, the research team produced some guidelines. These guidelines consisted in a series of short questions (Krueger & Casey, 2000) to direct each stage promoting participation and feedback. The questions-guide (Table 6.3) was tested in a simulated focus group with participation from a mixed group of health professionals and parents (two doctors, two nurses and two parents).

Table 6.3. Questions-guide to lead the Focus Groups.

	Stage 1	Notes
Question 1a	What is/was your day-to-day experience in the neonatology space in this hospital like?	
Question 1b	What do/did you do upon arrival?	
Question 1c	Where do/did you leave your things?	
Question 1d	Do/did you change clothes?	
Question 1e	Where did you speak to the doctors or support staff?	Only for the parent profile
Question 1f	Did you spend a long time on the ward?	Only for the parent profile
	Stage 2	
	Issue 1: Space aspects	
Question 2-1a	What do you remember of the space?	Only for the parent profile
Question 2-1b	What image comes to mind when you remember the period in which you were users of the service?	Only for the parent profile
Question 2-1c	How would you define the space?	
Question 2-1d	Is/was there enough space?	
Question 2-1e	How would you assess the light, smells, noise?	
Question 2-1f	What do / did you think about the general design?	
Question 2-1g	What is/was the best and the worst thing about the space?	
Question 2-1h	Is/was there anything you felt was missing in the space?	
Question 2-1i	Would you add anything if you were to redesign the space?	
	Issue 2: Emotional aspects	
Question 2-2a	How do/did you feel when you use the space?	
Question 2-2b	Could you associate different emotional states to specific moments and spaces?	
Question 2-2c	What are/were the general aspects that you feel influence/influenced your emotional state?	
	Stage 3	
Question 3a	Please give your global assessment of the space shown in the following pictures from 0 to 10, where 0 is the worst and 10 the best.	
Question 3b	Would you like to comment on any aspect of the space shown? Perhaps you forget to mention something, some positive or negative aspect.	
	Stage 4	
Question 4a	Please fill in the following questionnaire following the instructions it gives. Comment out loud on any difficulty.	
Question 4b	What do you think about the questionnaire itself?	
Question 4c	Is there any expression you do not understand for a specific case? Would you replace it with something else?	
Question 4c	Would you add an adjective or expression that helps you define an aspect of the space?	

2.1.3. Conduct

Before starting the sessions, the moderator presented the main objective of the focus group and its dynamics. Next, the participants' signed consent documents were collected. Then the session began following the questions-guide. When the questions-guide ended and the discussions were deemed exhausted, there was a brief review of the data felt to be most relevant in case any participant wished to add or qualify any aspect. Then the session was closed. Total duration of the focus group sessions was from 74 to 89 minutes which was sufficient to saturate the information contemplated in the questions-guide, without causing fatigue (Llopis, 2004). The conversations were audio-recorded for subsequent analysis, enabling information to be gathered on nuances of voice, tone and pauses.

2.1.4. Analysis

The analysis of the sessions was conducted as follows:

1. Pre-analysis. Immediately after each focus group session, group dynamics and the consistency of comments were analysed in order to detect any handicaps to be corrected in the focus group structure. It was found unnecessary to vary the structure or repeat any session.

2. Transcription. All focus group sessions were transcribed verbatim. Transcriptions were done by two members of the research team: one of them was the assistant interviewer. All the information that could provide identification was eliminated. Then, the transcriptions were revised by the rest of the research team who listened to all the recordings and agreed the result. The final texts were taken as the basis for analysing the focus groups (Krueger & Casey, 2000).

3. Structure of the analysis. In order to gather the concepts for use in semantic differential (Stage 1.1), the analytical method was organised in three phases. (a) First, a simple summative content analysis (Hsieh & Shannon, 2005) strictly recording the expressions from all the stages of the sessions; (b) second, sifting through the attributes from the questionnaire from stage 4 of the sessions; (c) third, grouping and filtering the expressions obtained in the previous stages. The first two stages were carried out independently by two members of the research team. The third stage, was carried out independently by two mixed groups formed by a doctor, a nurse, a parent and one of the interviewers. Subsequently, each researcher shared his/her analysis with his/her counterpart and presented a summary to the rest of the team to discuss discrepancies until a consensus was reached. In order to compile project recommendations (Stage 1.2) conventional content analysis (Hsieh & Shannon, 2005) was chosen because of the scanty literature available. Therefore, there were no initial categories. The procedure was carried out according to Graneheim & Lundman (2004), taking into account the content analysis techniques described by Krueger (1997).

2.2. Stage 2. Identification of the relevant design parameters in the assessment of the neonatology ward

The general aim of this stage is to identify the relevant design parameters in the assessment of the neonatal space. For this purpose, a field study was conducted between April and October 2014.

2.2.1. Subjects

The sample comprised 144 subjects of whom 34% were men and 66% women. 45% of the subjects who took part in the study were healthcare professionals (medical and nursing staff). The average age of participants was 37 years (Table 6.4). More women participated in the study than men because they are the majority users of this hospital infrastructure.

Table 6.4. Characteristics of the participants in the sample.

Gender			Age			Healthcare Professionals		
Male	49	34%	<30	6	4%	No Professional	127	88%
Female	95	66%	30-39	95	66%	Professional	17	12%
			40-49	36	25%			
			>50	7	5%			

2.2.2. Stimuli

A set of 18 pictures of neonatology wards (Figure 6.2) was produced and each of these was assessed by eight participants. These pictures were obtained from different hospitals and medical product catalogues. These wards were chosen because they provided sufficient variability in the set of relevant elements identified in the focus group study. The elements considered were: predominant colour in the department, separation between posts or cots, the availability of chairs or armchairs for family and companions, the possibility of natural light and the existence of purely decorative elements on floors and walls. It was then attempted to relate these elements to the defined affective and emotional variables. Given that all these variables are difficult to control in a study of real spaces, an attempt was made to randomise and thus avoid possible nesting. The affinity diagram technique was used to organise the information and find affinities in the chosen pictures after reducing the initial number to the final amount.

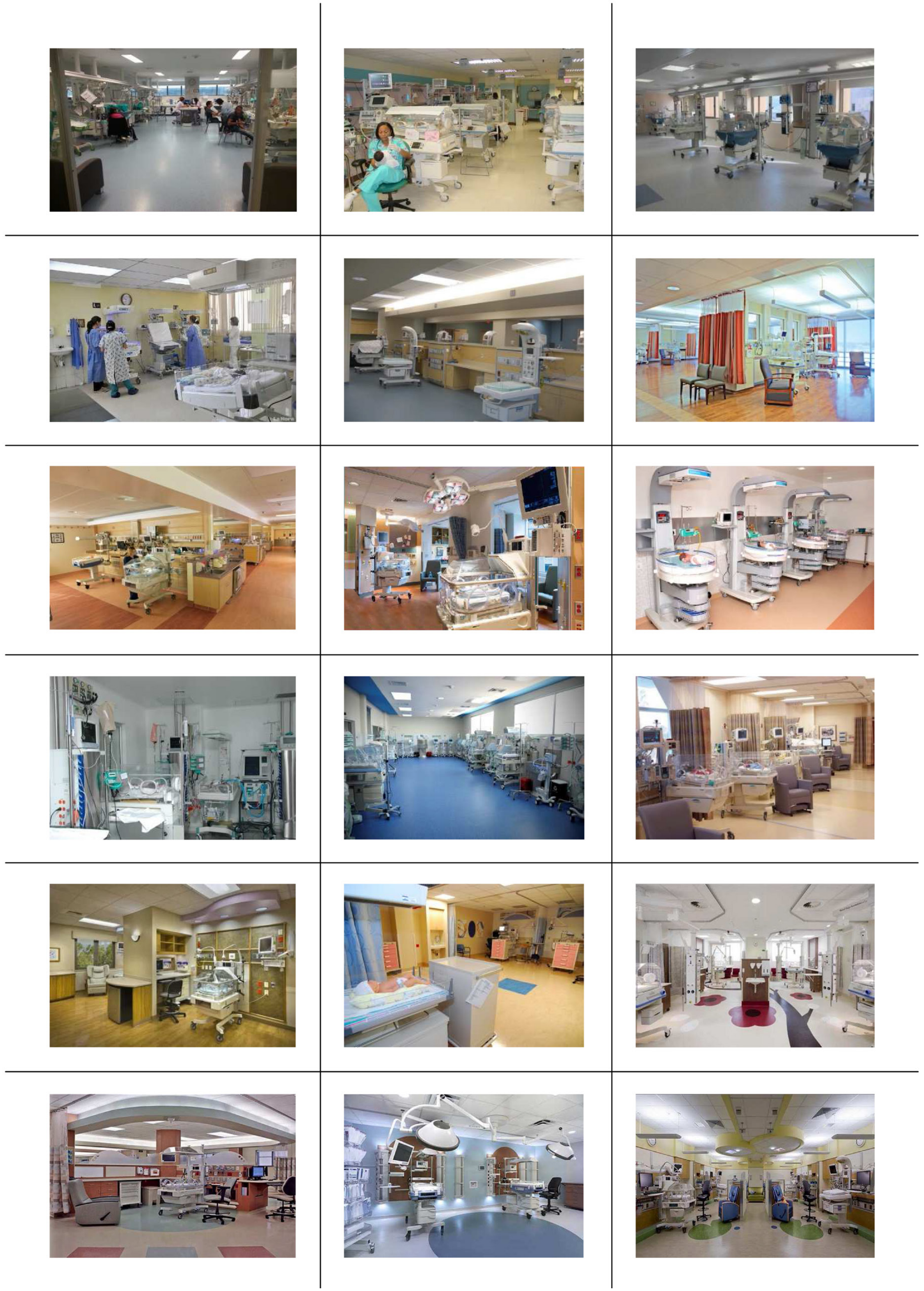


Figure 6.2. Set of neonatology wards pictures selected.

2.2.3. Questionnaire

The aim of the questionnaire was to collect subjective information on user perception of neonatology wards. This questionnaire collected four types of variables: (1) information on the subjects in the sample: gender of the users, age, number of children and profession (professional user profiles involved in the service, if applicable). (2) 25 adjectives or expressions that described the affective impression of ward users. These expressions were obtained after analysing the results from the focus groups with parents and medical and healthcare staff. The idea was to obtain a series of expressions able to describe perception of the study space. (3) Three emotions that the ward transmits, such as pleasure, arousal, dominance. These emotions come from the work by Mehrabian & Russell (1977). (4) Furthermore, the questionnaire collected a global evaluation variable from neonatology ward users and then divided it into aesthetic and functional levels. The assessment was based on a 5-point Likert scale to assess each image in relation to each of the chosen expressions: totally disagree, disagree, indifferent, agree and totally agree.

2.2.4. Data processing

After creating the database of user responses, statistical software SPSS 17.0 was used to process the data in three stages

1. Identification of the affective structure (Stage 2.1). To identify users' conceptual structure of this architectural space, principal component factor analysis was used to identify and extract the semantic axes. The number of components was chosen on the criteria that the eigenvalue of the components had to be greater than one because in that way it would provide more information than the original variables. After deciding the number of components the explained variance and the contribution of each original variable to each component were obtained. The components were interpreted using the Varimax rotation method. The interpretation was based on consideration of the original variables with the highest scores for each factor.

   Each component or semantic axis included a combination of adjectives from the original set that were highly correlated with each other and independent from other axes. These axes represent the user's conceptual structure and are used for the affective description of neonatology wards. Then Cronbach's Alpha was applied to measure the consistency of each factor (George & Mallery, 2003).

   Additionally, in order to test the relationship between the affective structure identified and the emotional structure (Mehrabian & Russell, 1977) the Spearman correlation coefficients between both structures were calculated.

2. Impact of the affective and emotional structure on the evaluation of the space (Stage 2.2). The impact of affective and emotional factors on the global evaluation of the space was quantified using linear regression analysis. In this case the global assessment variable was taken as the dependent variable and the set of affective factors and emotional factors (arousal, pleasure and dominance) were the independent variables.

3. Identification of the design parameters in the evaluation (Stage 2.3). Spearman's non-parametric correlations analysis was used to determine which design parameters had greater influence on perceptions. The set of design parameters and affective impressions to be taken into account in this analysis were identified as relevant in the previous stages.

3. Results

The results for Stage 1 and Stage 2 are shown below.

3.1. Stage 1. Exploratory analysis of the aesthetic and functional needs of neonatology ward users

Stage 1 led to two main results: (1) compilation of concepts to be used in Semantic Differential; and (2) compilation of project recommendations.

3.1.1. Stage 1.1. Compilation of concepts to be used in Semantic Differential

Analytical phase (a) provided 65 results and phase (b) reduced the initial 33 attributes in the questionnaire to 25. The 90 resulting attributes were reduced in phase (c) to a set of 25 that were not considered redundant and were sufficiently descriptive of various aspects of the space in neonatology wards and could be estimated through photographs by the general public. The final number in this reduction depends on the field study (Marco-Almagro, 2011), and in our case, it is the same order of magnitude as other studies with a similar scope (Mackrill, Jennings, & Cain, 2013; Mourshed & Zhao 2012). Table 6.5 shows the result for each phase. By way of example, quotes from two of the results obtained in phases (a) and (b) are listed below:

- Phase (a), attribute 32a. Informant P-2-7's memories about her experience: "I just remember feeling cold in the ward… I kept covering the child with a blanket".
- Phase (b), attribute 16b. Informant P-2-6's assessment of one of the photographs of neonatology spaces: "I love this room… It is huge. For me it is crucial, because you can leave the purse, the child's things… Without disturbing the nurses".

Table 6.5. Result of each analytical phase in the compilation of concepts to be included in Semantic Differential (phase c specifies the origin of the attributes).

				Phase (c)
Phase (a)	1a. Suitable	23a. Discrete	45a. Practical	
	2a. Up-to-date	24a. Elegant	46a. Private	
	3a. Pleasant	25a. Charming	47a. Professional	
	4a. Airy	26a. Eclectic	48a. Pretentious	
	5a. Spacious	27a. Confusing	49a. Excessively ornate	1. Intimacy (36a+42a+46a+52a)
	6a. Old-fashioned	28a. Specific	50a. Cosy	2. Child-friendly (35a+62a+20b)
	7a. Accessible	29a. Strict	51a. Limited	3. Welcoming (13a+59a+3b)
	8a. Attractive	30a. Exclusive	52a. Reserved	4. Homely (17b)
	9a. Beautiful	31a. Cool	53a. Satisfactory	5. Comfortable (10b+3a+16a+57a)
	10a. Well appointed	32a. Cold	54a. Secure/Safe	6. Exclusive (30a+34a+43a+55a)
	11a. Well furnished	33a. Hygienic	55a. Select/Exclusive	7. Attractive (8a+9a+12a+25a+44a+23b+30b)
	12a. Pretty	34a. Unassuming	56a. Simple	8. Elegant (24a+23a+60a+18b)
	13a. Warm	35a. Infantile	57a. Silent	9. Innovative (21b+2a+6a+40a+63a+64a+65a+31b)
	14a. Claustrophobic	36a. Intimate	58a. Sunny	10. Original (41a+27b+15a+20a+22a+31a+12b)
	15a. Colourful	37a. Clean	59a. Peaceful	11. Functional (19b+45a+13b)
	16a. Comfortable	38a. Modern	60a. Subtle	12. Professional (47a+1a+19a+53a+28a+8b)
	17a. Complex	39a. Natural	61a. Technological	13. Well equipped (7b+10a+11a+61a)
	18a. Worn out	40a. New	62a. Fresh	14. Safe (54a+29a)
	19a. Correct	41a. Original	63a. Typical	15. Quality (21a)
	20a. Curious	42a. Personal	64a. Usual	16. Modern (38a+26b)
	21a. Quality	43a. Poor	65a. Avant-garde	17. Claustrophobic (14a+50a+51a)
	22a. Dynamic	44a. Popular		18. Excessively ornate (49a+29b+17a+26a+27a+48a+9b)
Phase (b)	1b. Abstract	12b. Different	23b. Interesting	19. Cold (32a)
	2b. Accessible	13b. Efficient	24b. Clean lines	20. Spacious (5a+4a+16b)
	3b. Welcoming	14b. Basic	25b. Bright	21. Sunny (58a+39a)
	4b. Harmonious	15b. Essential	26b. Modern	22. Bright (25b)
	5b. Aseptic	16b. Spacious	27b. Original	23. Simple (56a+6b+14b+15b)
	6b. Basic	17b. Homely	28b. Pure	24. Clean (37a+18a+33a+5b)
	7b. Well equipped	18b. Formal	29b. Excessively ornate	25. Accessible (2b)
	8b. Competitive	19b. Functional	30b. Intriguing	
	9b. Complex	20b. Infantile	31b. Traditional	
	10b. Comfortable	21b. Innovative	32b. Urban	
	11b. Diaphanous	22b. Integrated	33b. Volumetric	

3.1.2. Stage 1.2. Compilation of project recommendations

The analysis provided six main categories: sensation of privacy, colours, design, lighting, spaciousness and equipment. Although each user profile had a focus characteristic of its specific use of the ward, there were no discrepancies between or within them and possible measures for satisfying requests were always compatible. Generally, we found intense demand for privacy on the part of parents, not always referred directly to the design of space. The group of healthcare professionals already knew about this and attempted to satisfy that demand. Focusing on more spatial aspects, there is a shared preference for colours other than those commonly used in hospitals, like white and green; for environments with carefully designed interiors and a child-friendly theme, not necessarily by using drawings and well-known characters; and for warm lighting, although more in reference to the temperature of the colour of artificial lighting or the colours of the interior itself, because, contrary to expectations, windows were usually the source of negative comments. All the user profiles emphasised the importance of more space. Parents asked for more space between cots and when discussing equipment, they suggested the need for separation between cots, usually after appraising privacy. This group also repeatedly requested comfortable chairs in which to spend the night (they did not consider beds to be essential) and to include toilets nearby, with showers if possible. Doctors also asked for sound-proofed bedrooms where they can rest while on duty, and nursing staff wanted staff rooms where they can meet and prepare food; both rooms need to be separate because in practice the two professional user profiles work at different rhythms. All user profiles agreed that the existence of individual lockers separated by user profile would be useful. Despite the shortfalls in design aspects found by the group of parents, there was intense appreciation of the staff and absolute approval of the treatment received thus providing further support for the irreplaceable nature of this aspect. Table 6.6 shows the categories and quotes assigned to them.

Table 6.6. Analysis of project recommendations.

Categories and subcategories	Example quote
1. Feeling of privacy	P-2-1: I think intimacy is important... I don't know if it is essential, / but it is very important. P-2-4: /Absolutely.
2. Colours	P-2-1: I would prefer light, pastel colours. But not the typical hospital colours.
3. Design	P-1-2: I like these design rooms. P-1-3: But I miss a more child-friendly aspect= P-1-2: =But Disney drawings aren't necessary. P-1-3: Yes, yes. I refer to rounded edges, colours...
4. Lighting	D-1-2: They are convenient (fluorescent lights) but I think they give a very sad light...don't you think so?
5. Spaciousness	D-2-3: It's good to have plenty of space P-2-5 Sometimes it looks like a junk room... With a bed and that's it and junk (especially medical monitoring instruments) and they are there, I don't know what they are for, but you can't move, because there is no space so you keep bumping into things.
6. Equipment	
a. Separation elements between cots.	P-2-1: It is not an intimate space to be with your baby... You're on show. There should be something to cover up.
b. Chairs so parents can stay the night.	P-1-3: I sleep really badly in those chairs, I wake up feeling terrible. P-1-2: Beds aren't necessary, they just need to be soft and reclinable.
c. Toilets for parents.	P-1-6: We had toilets nearby, that was good. If there was also a shower that would be great, because I spent many hours here and there were days when I went to work directly from the hospital... Or I had to go home to get ready for work.
d. Sound-proofed bedrooms for doctors.	D-1-3: Our bedrooms should be as sound-proofed as possible. D-1-1: We go there to rest and they (the nurses) might be taking or eating. It is not compatible [Collective agreement].
e. Staff rooms (meeting and kitchen).	N-2-2: A small kitchen with microwave, fridge and table. There's no need for anything else.
f. Lockers.	P-2-7: I had to carry a bag and the food I had prepared with me all the time... It's not convenient when you are with your baby. D-1-3: Now we have lockers on the other floor. It's ok, but it would be better to have them nearer.

3.2. Stage 2. Identification of the relevant design parameters in the assessment of the neonatology ward.

Stage 2 led to three main results: (1) identification of the affective structure; (2) impact of the affective and emotional structure on the evaluation of the space; and (3) Identification of the design parameters in the evaluation.

3.2.1. Stage 2.1. Identification of the affective structure.

Factor analysis reduced the 25 adjectives or expressions that described users' affective response to five independent factors that explained 69.72% of the variance of the original variables. Table 6.7 shows the factors chosen, their correlations with the original adjectives, and the percentage of variance explained and Cronbach's Alpha.

Table 6.7. Factor analysis and Cronbach's Alpha.

Axes	Factor	Semantic space included	% contribution	Cronbach's alpha
Axis 1	Privacy	Intimacy (0.795), Child-friendly (0.770), Welcoming (0.749), Homely (0.716), Comfortable (0.705), Exclusive (0.668), Attractive (0.650), Elegant (0.647), Innovative (0.571), Original (0.562), Modern (0.330), Cold (-0.347), Accessible (0.301).	21.830	0.930
Axis 2	Functional and Professional	Functional (0.882), Professional (0.806), Well equipped (0.796), Safe (0.786), Quality (0.744), Modern (0.654), Innovative (0.563), Clean (0.449), Accessible (0.380), Comfortable (0.371), Attractive (0.336), Original (0.311), Elegant (0.303).	19.976	0.926
Axis 3	Spaciousness	Claustrophobic (-0.765), Excessively ornate (-0.709), Cold (-0.704), Spacious (0.503), Attractive (0.440), Welcoming (0.419), Original (0.307).	11.075	0.864
Axis 4	Lighting	Sunny (0.791), Bright (0.725), Modern (0.451), Exclusive (0.376), Elegant (0.362), Original (0.360).	8.692	0.837
Axis 5	Cleanliness	Clean (0.791), Simple (0.634), Accessible (0.556), Spacious (0.417).	8.150	0.723

The factors or semantic axes represent the affective structure of neonatology wards. These axes represent concepts related to the privacy of the rooms, their functional and professional aspect, spaciousness and non-claustrophobic nature of the space, lighting and cleanliness.

From this semantic structure, the interest focuses mainly on Axis 1 which reflects the sensations related to privacy. This axis has the greatest variance explained (21.83% of the variance in the sample) and it is the initial perception that users use to distinguish or differentiate one neonatology ward from another. It reflects concepts such as intimacy, child-friendly, homely, comfortable, exclusive, among others. Axis 2 explains 19.98% of the total variance and reflects aspects like the functional and professional nature of neonatology wards including equipment, the sensation of safety and quality, and so on. Axis 3 is able to explain 11.07% of sample variance with aspects related to the perception of claustrophobia, spaciousness and so on. Axis 4 is related mainly to lighting and explains 8.69% of the variance. Finally, Axis 5 reflects the cleanliness and simplicity of the neonatology ward, also linked to accessibility. This last axis explains 8.15% of sample variability.

Cronbach's Alpha was used to measure the consistency of each factor and enabled us to estimate the reliability of each semantic axis through the variables that define it. All the semantic axes had a Cronbach's Alpha of more than 0.7, making them acceptable according to George & Mallery (2003).

Afterwards, Spearman's non-parametric correlations analysis was run to identify the impact of the affective structure on the emotional structure. The results show that the axes of privacy, functional-professional, and spaciousness, have a significant influence on the emotional response (Table 6.8). In particular, the importance of privacy on the generation of pleasure, the positive contribution of the functional-professional aspect in dominance, and the relevance of the spaciousness in stress reduction.

Table 6.8. Correlations among affective and emotional responses.

	E1. Arousal		A2. Pleasure		E3. Dominance	
	Correlation	Sig. level	Correlation	Sig. level	Correlation	Sig. level
A1. Privacy	.308	.000	-.634	.000	.269	.001
A2. Functional-Professional	-.195	.019	.186	.026	.710	.000
A3. Spaciousness	-.593	.000	.394	.000	.204	.014
A4. Lighting	-.137	.102	.126	.133	-.049	.562
A5. Cleanliness	-.091	.227	.043	.607	.115	.172

3.2.2. Stage 2.2. Impact of the affective and emotional structure on the evaluation of the space.

1. Impact of affective factors on the evaluation of the space. Linear regression analysis identified the relevant factors in the global assessment of a neonatology ward ($p<0.05$) (Table 6.9). The factor with the greatest influence on the global assessment is privacy, followed by aspects related to the perception of functionality and professionalism as well as spaciousness. Perceptions of luminosity ("sunny-light") and the cleanliness of the ward were not statistically significant.

Table 6.9. Affective factors ordered according to influence on the evaluation of the space (regression analysis)

Affective Factor	B	SE	Beta	t	Sig
(Constant)	-.396	.067		-5.873	.000
A1. Privacy	.854	.068	.628	12.623	.000
A2. Functional-Professional	.610	.068	.448	9.012	.000
A3. Spaciousness	.320	.068	.236	4.736	.000
A4. Lighting	.115	.068	.085	1.700	.091
A5. Cleanliness	-.038	.068	-.028	-.566	.572
R=.812					

2. Impact of emotional factors on the evaluation of the space. Linear regression analysis was also used to identify the emotional factors with the most influence ($p<0.05$) on the global assessment variable. In this case, the factors that reflected the emotions of dominance and pleasure had a significant influence. (Table 6.10).

Table 6.10. Emotional factors ordered according to influence on the evaluation of the space (regression analysis).

Emotional Factor	B	SE	Beta	t	Sig
(Constant)	-.289	.116		-2.485	.014
Arousal	-.122	.075	-,123	1.614	.109
Pleasure	.446	.092	.375	4.859	.000
Dominance	.453	.082	.374	5.505	.000
R=.727					

3.2.3. Stage 2.3. Identification of the design parameters in the evaluation.

Spearman's non-parametric correlations analysis was used to determine which design parameters had the greatest correlation with users' affective-emotional response. The perception of privacy correlated ($p<0.05$) with separation between different posts or cots, the existence of decorative elements and the availability of chairs or armchairs for companions. The perception of a functional and professional neonatology ward was negatively correlated with the presence of natural light, that is, closed wards, with artificial light are perceived as more professional. Finally, the perception of space was correlated with the presence of armchairs for family members as merely decorative elements with a slightly higher level of significance at 0.05, as well as with the separation between cots and the existence of natural light (Table 6.11).

Table 6.11. Correlations among affective response and design parameters.

	A1. Privacy		A2. Functional-Professional		A3. Spaciousness	
	Correlation	Sig. level	Correlation	Sig. level	Correlation	Sig. level
Separation between cots	.194	.020	-.093	.268	.152	.069
Natural light	-.017	.835	-.273	.001	.158	.059
Decorative elements	.250	.002	.078	.353	.338	.000
Cold colours	-.085	.312	.086	.304	.005	.952
Availability of chairs	.226	.006	.045	.589	.288	.000

Furthermore, for the factors reflecting the emotional response, Spearman's correlations analysis determined that the emotion of pleasure was correlated with separation between cots, decorative design elements in the wards and the presence of armchairs for family members to rest in. The sensation of dominance was positively correlated with decorative elements and negatively with the availability of natural light (Table 6.12).

Table 6.12. Correlations among emotional response and design parameters.

	E2. Pleasure		E3. Dominance	
	Correlation	Sig. level	Correlation	Sig. level
Separation between cots	.288	.000	-.044	.599
Natural light	.034	.689	-.210	.011
Decorative elements	.353	.000	.197	.018
Cold colours	-.141	.091	.098	.240
Availability of chairs	.207	.013	.124	.139

4. Discussion

This present study attempts to identify the set of affective and emotional factors behind the assessment of a Neonatology Unit space and propose design guidelines based on these factors.

The results have significant implications on two levels, contributing to the methodology and application. Figure 6.3 shows a diagram of the most relevant results.

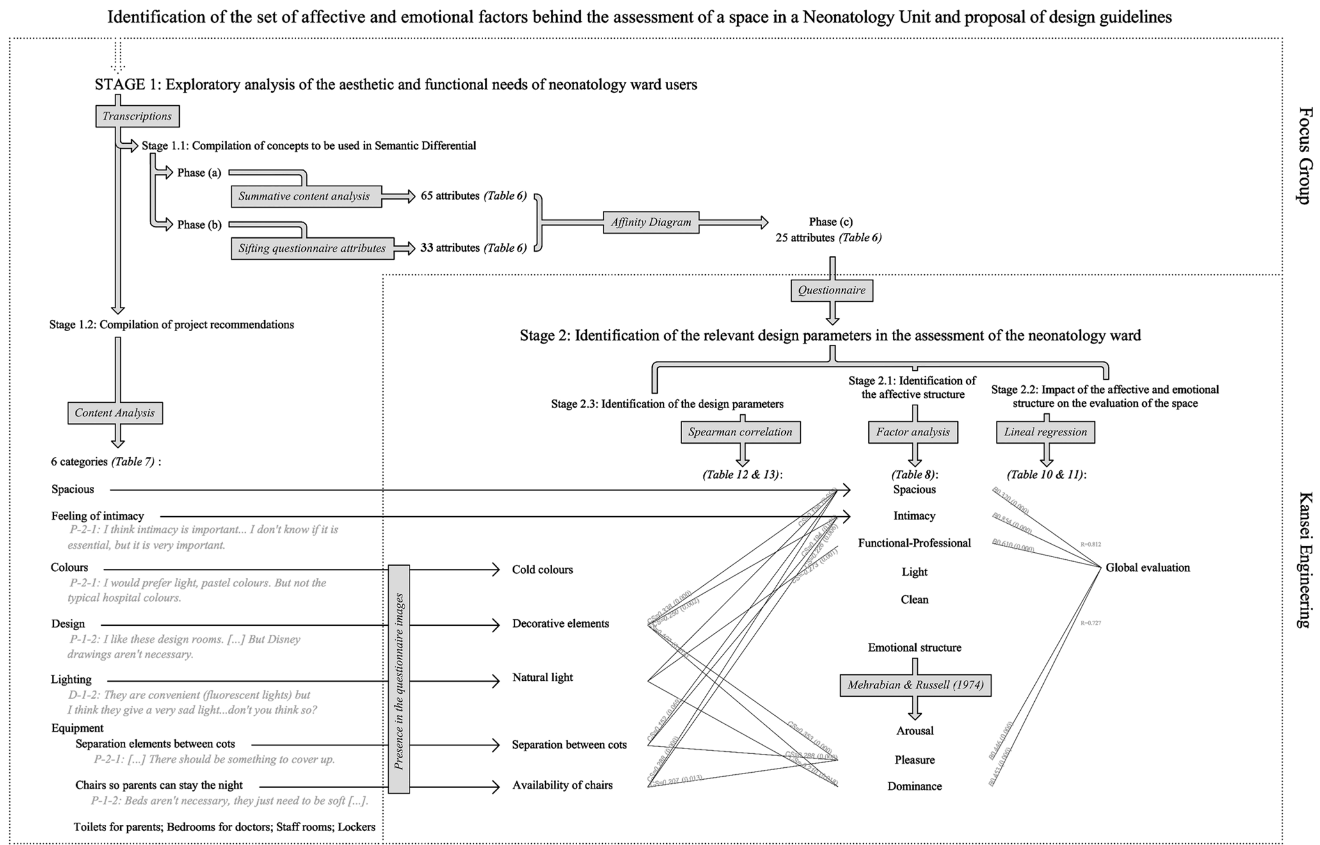


Figure 6.3. Diagram of the most relevant results.

From the methodological point of view, the most outstanding contribution is the combination of focus group and semantic differential in the context of Kansei Engineering. In the healthcare field, several studies have applied the focus group technique to extract recommendations for the design of waiting rooms (Biddiss et al., 2013), operating theatres (Watkins et al., 2011), nursing stations (Zborowsky, Bunker-Hellmich, Morelli, & O'Neill, 2010), wards (Lavender et al., 2015), and bathrooms (Fink et al., 2010). No works, however, have been found that apply Kansei Engineering as a stage prior to semantic differential. Furthermore, although semantic differential has been used to collect user responses to a variety of stimuli in hospitals like hospital sounds (Mackrill et al., 2013), the outside space (Fan, Kim, & Kim, 2012) or the treatments themselves (Ochiai et al., 2015), most of the questionnaires were produced directly by the investigators. Our main contribution is the combination of both techniques. Focus groups are used to make an initial diagnostic of service needs, extracting initial design recommendations based on user needs and collecting concepts for subsequent identification of the affective structure through semantic differential. Schütte, Eklund, Axelsson, & Nagamachi (2004) and Schütte & Eklund (2005) have argued that the use of both these techniques is ideal for obtaining the information required to build the semantic space. In turn, in our case, the focus group has also been used for contrast, by overlapping qualitative and quantitative data to produce reliable results.

The findings of this study make an important contribution to application.

Firstly, six main categories from the user view have been identified: sensation of privacy, colours, design, lighting, spaciousness, and equipment. Although it has been observed that the different user profiles have different needs, solutions to meet those categories are not mutually exclusive, supporting the idea that it is possible to achieve an optimum design common to different types of users (Day, 2003).

Secondly, in relation to the evaluators' affective structure. Five independent concepts have been identified which are able to explain 69.72% of the variance. These axes or factors are by order of explained variance: (1) privacy (21.83%), referring to an intimate and comfortable room; (2) functionality and professional nature (19.98%), related to the equipment and the sensations of safety and quality; (3) spaciousness (11.07%), related to the perception of claustrophobia; (4) lighting (8.69%), related to the bright and sunny look of the room; and (5) cleanliness (8.15%), that reflects simplicity and clean shapes and, to a lesser extent, accessibility. Similar results have been found in other works. Thus the axis "privacy" has been identified, among others by Leino-Kilpi et al (2001). These authors relate this sensation with room design, noise level, colours, temperature and the presence of other people. In the present paper, factor analysis also groups other terms such as "child-friendly", "homely", and "comfortable". There is a relationship with the study by Payne, Mackrill, Cain, Strelitz, & Gate (2015) in this line, which identifies atmosphere as an important dimension in the design of well-being centers. This dimension gathered aspects like "homely", "comfortable", and "cheerful. The concept of "spaciousness" is also identified in other studies in, for example, Codinhoto, Tzortzopoulos, Kagioglou, Aouad, & Cooper (2009) and "spatial" and "maintenance" factors in Mourshed & Zhao, (2012). Generally, spaciousness has been much studied, for example analysing the relationship with medical outcomes (Hellier, Edworthy, Derbyshire, & Costello, 2006; Hignett & Masud, 2006; Zimring, Joseph, Nicoll, & Tsepas, 2005) stressful environments (Stamps, 2007) and even user satisfaction (O'Neill, 1994). "Lighting" has also been the subject of many studies. Mourshed & Zhao (2012) combine it with noise in the "environmental" dimension and Codinhoto et al. (2009) in the factor labelled as fabric/ambient which also includes materials, acoustics, temperature and humidity. "Cleanliness" is labelled as the "maintenance" dimension in Mourshed & Zhao (2012) and Codinhoto et al. (2009). This aspect has been assessed in hospital environments mainly because of its relationship with infections (Dancer, 2011). Finally, "functionality" is the only factor which does not appear in other studies in a healthcare setting, but it is a relevant concept in studies on the assessment of space and appears to reflect the ability to understand the environment. It is labelled as "functionality", "comprehension" (Bishop & Rohrmann, 2003; Rohrmann & Bishop, 2002; Wergles & Muhar, 2009) and "legibility" (Kaplan, 1987, 1992).

Thirdly, in relation to the importance of affective and emotional factors with the overall assessment of the space, the results show that the perception of privacy and sensations of dominance and pleasure are fundamental for a positive assessment of the space. These findings are in line with Williams (1987) and Davies & Peters (1983) who highlight the importance of privacy because of its impact on patient stress, with noise identified as a fundamental component of privacy. Furthermore, Lambert, Coad, Hicks, & Glacken (2014) relate privacy with degree of control or sensation of dominance and highlight the importance of both aspects.

Fourthly, in relation to design elements, the results show six main aspects:

1. Provide spacious surroundings which could be related to the explicit need for personal space (Evans & Howard, 1973), defined as the area surrounding individuals which they try to preserve to feel safe (Dosey & Meisels, 1969; Sommer, 1959), and is related to the next recommendation.
2. Facilitate sufficient separation between posts or cots to improve privacy and the sensation of pleasure. Barlas, Sama, Ward, & Lesser (2001) studied the advisability of separations between patients to conserve privacy, with solid walls being better than curtains. Lambert et al. (2014) also report a similar finding.
3. Use different colours from those usually found in healthcare centres, as some aversion was found to white and especially green. This result is comparable to Park's (2009) finding that users of paediatric services preferred blue and green to white; Lambert et al. (2014) conclude that children prefer primary colours like green and yellow; and Christenfeld, Wagner, Pastva, & Acrish (1989) who found that flooring tiles with the best assessments were light coloured.
4. Design areas with childhood themes, to improve the sensation of privacy, spaciousness and the emotions of pleasure and dominance. The use of childhood themes without explicit distinctive elements is in line with the studies by Ullán et al., (2012) and Blumberg & Devlin (2006) of adolescents in relation to hospitals.

5. Use warm artificial light which, unlike natural light, is related to professionalism and dominance. In this case, our findings differ from other works which report that natural light usually scores better than artificial light (Beauchemin & Hays, 1996, 1998; Lambert et al., 2014; Walch et al., 2005), but it may be related to the presence of windows. Although it has basically been demonstrated that light has a positive effect on patient experience (Ulrich, 1984; Verderber, 1986; Verderber & Reuman, 1987), the relationship is more complex (Aries, Veitch, & Newsham, 2010); and bearing in mind the "prospect and refuge theory" (Appleton, 1975), in certain cases (mobility difficulties and a marked need for privacy), light could also provoke a sensation of invasibility or lack of dominance related to the factors of "being alone" and "fear of strangers" that Russell (1979) identifies.
6. Choose user-friendly equipment: for family members, comfortable armchairs in which to spend the night, personal lockers and bathrooms with showers near to cots, sound-proofed bedrooms where doctors can rest when they are on call and multipurpose meeting rooms for nursing staff. Other works have identified that rooms with better quality, modern, attractive furniture, sofas, bathrooms with baths, sound-proofed walls and living rooms with a dining room for families generate greater satisfaction (Janssen, Klein, Harris, Soolsma, & Seymour, 2000; Olsen, 1984).

The limitations of this work are given by the stimulus used. The sample of neonatology wards presents a broad range of variability because we have attempted to show a set of spaces or wards that are representative of the true situation. However, this approach may lead to a given combination of design elements in the images. To control for this effect would require an excessively large sample of images to reflect all the possible combinations of attributes. The solution adopted in this case has been to include these attributes in a random manner (Kish, 1995).

In future works it would be interesting to analyse the effect on the user of each determinant design parameter in isolation using virtual images of spaces rather than real spaces. Furthermore, it would also be interesting to validate the results obtained in this study through pre- and post-occupancy evaluation during the design of a new Neonatal Unit.

5. Implications for Practice

- There are five key affective factors to consider when designing a Neonatology Unit space: privacy, functionality and professional nature, spaciousness, lighting and cleanliness.
- The following design guidelines for a Neonatology Unit space were identified: provide spacious surroundings, facilitate sufficient separation between the different posts or cots, use different colours from those usually found in healthcare centres, design areas with childhood themes, use warm artificial light and choose user-friendly equipment.
- The combination of Semantic Differential and Focus Group is useful to identify the set of affective and emotional factors behind the assessment of a space and propose user-centred design guidelines.

07

Artículo 5

Paper 5

"Multisensory stress reduction: A neuro-architecture study of paediatric waiting rooms".

Este artículo fue publicado en la revista "Building Research & Information" (ISSN 2045-2322). Es una revista internacional, revisada por pares (siguiendo una double-blind review), centrada en todo el ciclo de vida de los edificios: desde su diseño a su uso. Así, la revista incluye investigaciones sobre temas variados, que abarcan cuestiones relacionadas con los usuarios, el rendimiento, las políticas, los procesos creativos, y la ejecución de las edificaciones. La revista "Building Research & Information" es referente en áreas de conocimiento como la construcción y la tecnología de la construcción; estando indexada en SJR (Q1 – 1.175 en 2019, última anualidad disponible; categorías "building and construction" y "civil and structural engineering") y JCR (Q1 - 3.887 en 2019; categoría "construction & building technology" - 12/63). Según *Google Scholar*, hasta la fecha este artículo ha sido citado 9 veces.

Higuera-Trujillo, J. L., Llinares, C., Montanana, A., & Rojas, J. C. (2020). Multisensory stress reduction: a neuro-architecture study of paediatric waiting rooms. *Building Research & Information*, *48*(3), 269-285. DOI: https://doi.org/10.1080/09613218.2019.1612228

This paper was published in the journal "Building Research & Information" (ISSN 2045-2322). It is an international, peer-reviewed journal (following a double-blind review), focusing on the entire life cycle of buildings: from design to use. As such, the journal includes research on a variety of topics, covering issues related to users, performance, policy, creative processes, and building performance. The journal "Building Research & Information" is a reference in areas of knowledge such as construction and building technology; it is indexed in SJR (Q1 - 1,175 in 2019, last available annuity; categories "building and construction" and "civil and structural engineering") and JCR (Q1 - 3,887 in 2019; category "construction & building technology" - 12/63). According to Google Scholar, this paper has been cited 9 times to date.

Higuera-Trujillo, J. L., Llinares, C., Montanana, A., & Rojas, J. C. (2020). Multisensory stress reduction: a neuro-architecture study of paediatric waiting rooms. *Building Research & Information*, *48*(3), 269-285. DOI: https://doi.org/10.1080/09613218.2019.1612228

Abstract

The implementation of environmental satisfaction sources in the design of a health centre is a means to achieve stress reduction. The present work analyses the effect that these sources have on the stress reduction of patients' companions in a paediatric service. A two-phase study was carried out. During the first phase, 120 participants assessed 20 waiting rooms in situ in order to select the environmental sources with the greatest effect. During the second phase, the stress levels of 26 participants were measured in four simulated waiting rooms that combined the selected sources from the first phase. A multisensory simulation was carried out through a virtual reality experiment with visual, auditory and olfactory elements, and stress levels were measured at the psychological and neurophysiological levels. Results suggest that a combination of environmental satisfaction sources creates an important synergistic effect at the psychological and neurophysiological levels and underlines the importance of auditory and olfactory stimuli. Conclusions may be of interest to designers and managers of healthcare facilities.

1. Introduction

Stress is an interrelation between a subject and the environment that occurs when the subject evaluates his or her resources as insufficient to meet the demands of the environment (Lazarus & Folkman, 1984). In healthcare, this state can cause a wide variety of negative effects that worsen patients' recovery and satisfaction (Ulrich et al., 2004). Paediatric services represent a special challenge because of unforeseen behaviours and levels of stress that children may display (Gorski, Slifer, Kelly-Suttka, & Lowery, 2010). Despite the importance of stress in this context, 50% of patients still consider health centres stressful (Gates, 2008), suggesting that more needs to be done in the design and management of paediatric waiting rooms.

This stress not only affects patients but also extends to staff and patients' companions. Scholars have found that stress influences staff health (Devereux, Rydstedt, Kelly, Westo, & Buckle, 2004) and execution of errors (Scott, Hwang, & Rogers, 2006). A child's stay in hospital can also be highly stressful for companions. Among children's companions, stress is associated with a series of physical and psychological outcomes that include anxiety, depression, fatigue and interruption of sleep (Busse, Stromgren, Thorngate, & Thomas, 2013), which has further negative effects on the child (Whelan & Kirkby, 2000). Companions' stress has scarcely been studied, and, in the case of parents, mitigation measures are mainly based on their psychological preparation to face the situation.

Stress in healthcare facilities is caused not only by the illness and the related medical procedures but also by the context. Many studies have shown that it is possible to address the psychological state of patients and companions by means of space design (Leather et al., 2003), which may even have a healing effect (Zhang et al., 2019). However, these studies generally have limitations: (1) they focus on analysing one isolated variable, whereas real spaces have a combination of variables (Andrade & Devlin, 2015); (2) the quantification of stress is carried out through self-reports, which are subject to biases (Schwarz & Strack, 1999) such as the participants' difficulty in expressing psychological status; and (3) where environmental simulations are used as stimuli, they are usually photos or plans, which evoke different psychological responses from those evoked by the physical spaces that they represent (Higuera-Trujillo, López-Tarruella, et al., 2017).

The objective of this study is to analyse the effect that certain characteristics of the design of paediatric waiting rooms have on companions' stress reduction, addressing the aforementioned limitations. Using neurophysiological and psychological measures, we analyse the effect of combinations of different environmental satisfaction sources on stress levels. Virtual reality was used for the environmental simulation. The choice of context was based on the fact that waiting rooms are spaces used by the general public and, in particular, that paediatric waiting rooms cause high levels of stress in children and their companions.

1.1. The effect of healthcare facility design on stress

Various theoretical frameworks of healthcare environmental design and emotional support have been developed. In these frameworks, emotional support is interpreted as the actions carried out to support psychological needs and promote health and healing through the design of spaces in healthcare facilities (Schweitzer, Gilpin, & Frampton, 2004). One of the principal frameworks is Ulrich's theory of supportive design (1991). According to this framework, healthcare facilities have to foster three components: sense of control, social support and positive distractions. Many applied studies have been based on this framework. For example, it has been shown that different aspects of hospital rooms contribute to stress reduction (Andrade, Devlin, Pereira, & Lima, 2017) and that the sense of control affects companions in similar contexts to paediatric waiting rooms (Suter & Baylin, 2007). In addition to this framework, others have focused on taking account of patients' needs in the design process, citing 'interior design features', 'architectural features', 'maintenance features', 'social features' and 'ambient environment features' (Harris, McBride, Ross, & Curtis, 2002). In general, this discussion shows that interest in this dimension of health spaces has risen in recent times.

In most studies, the quantification of stress levels is carried out by means of self-report. This analysis, whether carried out through quantitative, qualitative or combined means (Higuera-Trujillo, Montañana i Aviñó, et al., 2017), is limited when registering participants' unconscious processes or when studying them in real time (Reinerman-Jones et al., 2013). Thus, the state reported by the user may differ from the reality, and state variations are difficult to study because the report covers a broad time segment. In this regard, the technologies applied in neuroscience can contribute by offering a higher level of objectivity. These technologies cover several manifestations of the nervous system. Among them are electrodermal activity (EDA), which measures variations in skin perspiration, electrocardiograms, which measure heart rate variability (HRV), and electroencephalograms (EEGs), which measure variations in the electrical activity on the surface of the scalp. A considerable amount of literature has presented analyses to obtain stress metrics (Campbell & Ehlert, 2012). These analyses can enhance knowledge about stress reduction through design.

1.2. Design variables

The environmental satisfaction sources studied in the literature focus on healthcare facilities and different sensory modalities. Accordingly, it is possible to find analyses focused on visual, auditory and olfactory variables.

In the visual modality, nature and design variables have been most frequently studied. In general, they can improve the user experience. They have been widely studied as sources of satisfaction, and they have even been proposed as therapy (Avrahami, 2006).

- Regarding nature, Ulrich (1991) proposed design patterns based on wild nature for healthcare facilities. Related studies have shown that this positive effect extends even to realistic nature photographs, reducing patients' stress (Nanda, Eisen, Zadeh, & Owen, 2011) and improving evaluations of waiting rooms (Beukeboom, Langeveld, & Tanja-Dijkstra, 2012).
- Regarding design, it has been shown that lighting, colour and architectural design variables generate the perception that better medical attention is being offered (Baker & Cameron, 1996). In this regard, it has been suggested that neuro-aesthetics can provide a source of pleasure in the healthcare environment (Nanda et al., 2009). The placement of furniture, even without modifying the architectural configuration, also has this capacity (Arneill & Devlin, 2002).

In the auditory modality, music and sounds of nature variables have frequently been studied both independently and in conjunction with visual ones. Including this type of stimuli can facilitate the health processes faced by the patient without negatively influencing the staff's responsibilities (Waldon & Thom, 2015).

- Music can contribute to reducing stress levels in both controlled laboratory conditions (Thoma et al., 2013) and in healthcare (Moola, Pearson, & Hagger, 2011). For example, it has been found that music reduces patients' pain in pre-operative (Lee, Chao, Yiin, Chiang, & Chao, 2011) and post-operative situations (Özer, Özlü, Arslan, & Günes, 2013) and in emergency service waiting rooms (Holm & Fitzmaurice, 2008). This stress-reducing effect has also been found in the case of companions (Routhieaux & Tansik, 1997).
- Sounds of nature can reduce the stress levels of patients (Saadatmand et al., 2013). It has also been found that they reduce the pain of invasive procedures combined with related visual stimuli (Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003).

In the olfactory modality, these stimuli have been found to have a positive effect on psychological and behavioural processes (Herz, 2009). A variety of scents have been studied, notably lavender and orange. However, although aromatherapy implementation in healthcare facilities has a long history and significant benefits (Cannard, 1996), this modality has been addressed by few studies.

- Lavender is one of the most frequently studied fragrances (Fenko & Loock, 2014). It has been observed to have benefits in reducing stress in neonatal (Kawakami et al., 1997), needle insertion (Kim et al., 2011), postpartum (Kianpour, Mansouri, Mehrabi, & Asghari, 2016), and palliative care contexts (Berger, Tavares, & Berger, 2013). In the staff sector, this scent also contributes to reducing stress (Sung & Eun, 2007) and improving performance (Birnbach, King, Vlaev, Rosen, & Harvey, 2013).

- The scent of orange, although it has been less widely studied, has been shown to reduce stress in healthcare facilities. Contexts where this effect has been observed include women waiting in the dentist's office (Lehrner et al., 2000) and pregnant women in childbirth units (Rashidi-Fakari, Tabatabaeichehr, & Mortazavi, 2015).

More often than not, these studies use photographs or videos to simulate the environmental satisfaction sources. Although this approach may be valid, it has certain weaknesses. Among other weaknesses, photographs and videos lack interactivity, are subject to external distractors, and do not reproduce olfactory stimuli. Consequently, experience differs substantially from reality (de Kort et al., 2003). In this sense, virtual reality can contribute by generating multisensory experiences that are more similar to reality because it can provide visual, auditory and olfactory simulation. Thus, it offers the chance to develop experiences which generate a sense of presence or 'being there' (Steuer, 1992), in an immersive interactive simulation. Moreover, viewed in head-mounted displays (HMDs), visual information of the physical environment is completely replicated. Consequently, using these technologies can help us reach new conclusions about the psychological effect of space design.

2. Method

The method was structured in two phases. Both phases were oriented toward studying the effect that different environmental satisfaction sources in paediatric waiting rooms have on companions' stress. This division allowed to limit the number of sources to be analysed: in the first phase, the sources with greater effect in reducing stress were identified in physical waiting rooms; and in the second phase, these sources were analysed in an isolated and combined way under controlled laboratory conditions. Table 7.1 shows the most relevant features.

Table 7.1. Most relevant features of the general methodology.

Phase and objective	Material and method	Analysis	Anticipated result
Phase I Identify the environmental satisfaction sources of the waiting-rooms which have a higher incidence on the companion's stress reduction	Field study: *in situ* N: 120 fathers/mothers Stimuli: 20 waiting-rooms Material: questionnaire Dependent variables: "contribution to stress reduction" y "perceived stress"	Phase I: Analysis of the individual effects of the environmental satisfaction sources on stress reduction	Inventory of the environmental satisfaction sources which have a higher incidence on stress reduction
Phase II Identify how the CESS (combinations of environmental satisfaction sources) of the waiting-rooms influence the companion's stress reduction	Field study: environmental simulation in a laboratory N: 26 fathers/mothers of children Stimuli: four environmental simulations de waiting-rooms, each one with a different CESS based on the results of Phase I Material: presence and stress questionnaires, and neurophysiological acquisition devices Dependent variables: psychological ("level of presence", and "perceived stress"); and neurophysiological (registers of "EDA", "HRV", and "EEG")	Phase IIA: Analysis of levels of presence in CESS simulations Phase IIB: Analysis of psychological stress metrics and their relationships Phase IIC: Analysis of neurophysiological metrics related to stress Phase IID: Relationship between neurophysiological and psychological metrics	Inventory of the contributions of stress reduction (at psychological and neurophysiological levels) of different CESS

The general characteristics of the two phases are as follows:

In Phase I, we identified the environmental satisfaction sources in paediatric waiting rooms that have the greatest effect on companions' stress reduction. This was done by reviewing the relevant literature, which resulted in 19 sources. The field study was carried out in situ, given that context could affect the responses. In this phase, 120 children's companions assessed the effect of 19 environmental satisfaction sources (see Figure 7.4) on stress in 20 paediatric waiting rooms located in Spain. These waiting rooms were located in the Valencian Community, a Mediterranean region located in the southeast of Spain with approximately 5 million inhabitants. In this region, we selected representative waiting rooms of municipalities with more than 50,000 inhabitants, using the technique of reduction of the affinity diagram. The number of 20 waiting rooms offered a sample that the research team considered sufficiently representative and differentiated of waiting room designs. A stress self-assessment was also used to ensure that the participants were in a highly stressful situation when they assessed sources. Our results show the environmental satisfaction sources with the greatest effect on stress reduction for the context studied.

In Phase II, we identified the combination of environmental satisfaction sources (CESS) identified during Phase I that had the greatest effect on stress reduction. The field study was carried out in a laboratory, using immersive virtual reality systems. In this study, 26 children's companions were exposed to four different CESS in a virtual waiting room, and psychological and neurophysiological responses related to stress were observed. Simulations were validated through the participants' sense of presence, measured through psychological responses (Phase IIA). Subsequently, psychological and neurophysiological responses were obtained to analyse participants' stress levels. For psychological responses, stress self-assessments were used. For neurophysiological responses, the metrics of EDA, HRV and EEG were used. The results show the effect of CESS on stress reduction at the psychological (Phase IIB) and neurophysiological (Phase IIC) levels and the relationship between their metrics (Phase IID).

3. Materials and Methods

This section describes the materials and methods used in Phase I and Phase II.

3.1. Phase I

Phase I focused on identifying the environmental satisfaction sources with the greatest effect on stress reduction. A sample of participants in a real waiting situation in physical waiting rooms completed a questionnaire on the impact of different sources of environmental satisfaction on stress. The questionnaire also assessed their state of stress.

3.1.1. Participants

Participants were 120 fathers or mothers of children who are users of a paediatric service. The sample was gender balanced (60 women and 60 men), and the average age was 37 years (σ = 6.77). The selection was based on the criterion that companions be within the first degree of consanguinity, the most common children's companion profile.

3.1.2. Stimuli

The stimuli were applied in 20 paediatric service waiting rooms in various healthcare institutions (both in hospitals and in community health centres). We tried to compile a varied set, given the 'nesting' limitation that can arise when working with real stimuli (Kish, 1995). Each room was assessed *in situ* by six participants (three men and three women).

3.1.3. Questionnaire

Two types of questions were asked of each participant:

- Assessment of the stress level in each waiting room with the question 'At this moment, I feel a stress level…' followed by a Likert scale ranging from -2 to 2 in increments of half points.
- Assessment of the contribution of 19 environmental satisfaction sources that are characteristic of waiting room spaces in general in terms of their effect on stress reduction. The selection of these sources was carried out by the work group (consisting of two members of the research team, two external architects, two fathers and two mothers of children who use a paediatric service), taking into consideration the bibliography and previous visits to the 20 waiting rooms considered in the study. The environmental satisfaction sources were 'space for baby buggies', 'furniture arranged facing one another', 'furniture arranged in groups', 'silence', 'sounds of nature', 'adjustable lighting in each section of the waiting room', 'furniture arranged not facing one another', 'space for companions', 'non-intense lighting', 'appropriate signage', 'adjustable temperature in each section of the waiting room', 'nature pictures', 'natural lighting', 'vending machine', 'nice scent', 'pictures for children', 'non-intense music', 'vegetation' and 'play facilities for children'. The assessment was performed using the question 'For the waiting rooms of the paediatric service in general, this source contributes to reducing stress…' followed by a scale ranging from 0 to 10.

The participants completed the questionnaire during their waits in the stimuli rooms. They all waited for between 15 and 30 minutes to mitigate possible differences, given that this is an important factor in these experiences (Magaret, Clark, Warden, Magnusson, & Hedges, 2002).

3.1.4. Data analysis

After the database had been compiled and anonymized, the statistical analysis was carried out. The average of each environmental satisfaction source was obtained to identify the sources that have the greatest effect on stress reduction. IBM SPSS software was used (v.17.0; www.ibm.com/products/spss-statistics).

3.2. Phase II

Phase II focused on identifying how a combination of CESS has an influence. For that purpose, participants in a stressful situation (generated by means of a psychological stressor) were exposed to different CESS in a waiting room through environmental simulation set-ups, and psychological and neurophysiological metrics of the stress levels were recorded. All participants visualized a training scenario for a few minutes before starting the experiences to improve their adaptation to the virtual reality set-up. Figure 7.1 shows the general sequence.

	CONCEPT	TIME (MINUTES)	
Pre-experiences	**BEGINNING WITH THE PARTICIPANT** Reception, basic instructions, signature of the consent, demographical questionnaire, adaptation to virtual reality set-up, and placement of neurophysiological acquisition devices. Recorded data: psychological data related to stress (metric: Trait Anxiety Inventory)	≈10	↓
	BASE LINE Open Eyes + Closed Eyes Recorded data: neurophysiological data retated to stress (base-line metrics: EDA-Phasic, EEG-Highbeta, EEG-AAPEn)	4 (2+2)	
	STRESSOR SETTING TASK Arithmetical task to adjust the difficulty of the stressor	1	
	INSTRUCTIONS *"Now you are going to listen to a recording and carry out a task. Then, you will be immersed in a space. Imagine that it is a waiting room in the paediatric service. You are waiting for your turn with your child, who you are accompanying for a checkup of certain importance.Wait sitting.After that, answer some questions about how you feel. There are no correct or incorrect answers. Don't spend too much time, but give the answer that best describes yourself. This will be repeated 4 times.*	≈2	
CESS-experiences (repited for each CESS)	**PREPARATION AUDIO** Preparation relaxing audio before the stressor task (to avoid excesive fatigue with the repetition of the sequence) During this period the room is ventilated to avoid accumulation of smells	2	↓ CESS#1 → CESS#2 → CESS#3 → CESS#4 (counterbalanced)
	STRESSOR Arithmetic tasks.	2	
	STRESSOR VERIFICATION Recorded data: psychological data related to stress (metric: stress self-assessment)	≈0.5	
	EXPERIENCE OF THE CESS Environmental simulation of the assigned CESS (the interviewer adjusted the virtual reality technologies) Recorded data: neurophysiological data related to stress (metrics: EDA-Phasic, HRV-LFHF, EEG-Highbeta, EEG-AAPEn)	2	
	ASSESSMENT OF THE EXPERIENCE Recorded data: psychological data related to stress (stress self-assessment, and State Anxiety Inventory), and psychological data related to presence (SUS questionnaire)	≈5	
Post-experiences	**ENDING WITH THE PARTICIPANT** Removal of the devices, accompaniment to the exit.	≈5	↓
	TOTAL	≈67	

Figure 7.1. General sequence of Phase II.

3.2.1. Participants

Participants were 26 fathers or mothers of children in the paediatric service. The data for two participants were removed because of neurophysiological acquisition problems in one case and the exclusion criteria described below in the other. The final sample (24) was gender balanced (54% male and 46% female), and the average age was 37 years (σ = 3.99).

There were three selection criteria: children should be users of the paediatric service, should not suffer from any condition with contraindications for the use of virtual reality technologies, and should have normal or corrected-to-normal vision with contact lenses.

3.2.2. Psychological stressor

Before experiencing the CESS, the participants were exposed to a psychological stressor. This consisted of the performance of arithmetic tasks, for 120 seconds, based on the Montreal Imaging Stress Task (Dedovic, Renwick, Mahani, & Engert, 2005) and adapted for difficulty for each subject by means of a previous task.

With the aim of verifying stress generation, the interviewer asked the participants to self-assess their stress levels using a Likert-type scale ranging from -2 to 2. All participants reported high stress levels (X = 1.41, S = 0.590), so the stressor was considered appropriate. Although the stress generated by this method may differ from the experiences that the experiment is designed to simulate, it is an appropriate approximation in laboratory conditions (Moya-Albiol & Salvador, 2001).

3.2.3. CESS configurations

The base stimulus was always the same (a visual, auditory and olfactory replica of the real waiting room that was considered standard). On this base stimulus, three different CESS were implemented. The choice of environmental satisfaction sources was based on the results of Phase I ('nice scent', 'pictures for children', 'non-intense music', 'vegetation' and 'play facilities for children') in order not to make the combinations so complicated as to be impracticable. The play facility for children was fixed as a constant because it is common in Spain, and the other four were grouped according to their affinity described by Harris et al. (2002) with 'interior design features' (vegetation and pictures for children) and 'ambient environment features' (non-intense music and a nice scent). Specifically, the composition *Miserere mei, Deus* by Gregorio Allegri (Thoma et al., 2013) and the scent of lavender (Fenko & Loock, 2014) were chosen because they were evaluated as relaxing. In this way, four CESS configurations were developed. Table 7.2 specifies each CESS configuration, according to the sensory modalities. All the participants were exposed to the four configurations, following an incomplete counterbalancing design.

Table 7.2. CESS configurations, according to the involved sensory modalities.

CESS	Sensory modality: Visual		Auditory		Olfactory	
	Standard waiting-room replica	Vegetation, and pictures for children	Standard hospital ambient noise	Relaxing and non-intense music	Standard hospital simulation scent	Nice relaxing scent
CESS#1	X		X		X	
CESS#2	X	X	X		X	
CESS#3	X		X	X	X	X
CESS#4	X	X	X	X	X	X

3.2.4. Environmental simulation set-ups

The CESS experiences were carried out by means of visual, auditory and olfactory environmental simulations. The following devices were used:

- HTC Vive. Visual stimulation. An HMD developed by HTC and Valve (www.vive.com). This displays 2160×1200 pixels (1080×1200 per eye) with a field of view of 110 degrees and a 90Hz refresh rate. Figure 7.2 shows both types of CESS configurations (CESS#1 and CESS#2; CESS#3 and CESS#4) at the visual stimulation level.

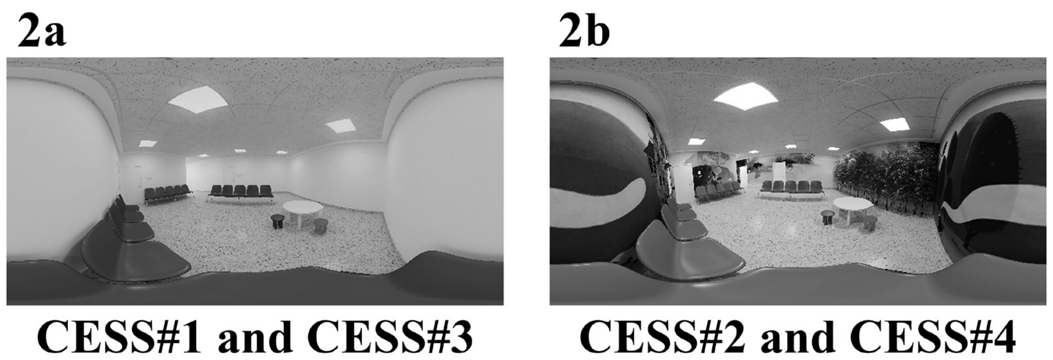


Figure 7.2. CESS configurations at visual level stimulation.

- HD 558. Auditory stimulation. Headphones developed by Sennheiser (www.en-us.sennheiser.com). Two types of CESS configurations were reproduced at auditory level: CESS#1 and CESS#3, a binaural recording of the ambient noise in a paediatric waiting room; and CESS#2 and CESS#4, the simulation of a loudspeaker system broadcasting *Miserere mei, Deus*.
- Scentpalette. Olfactory stimulation. Aromatizing device developed by HeadHunter 2000 (www.scentpalette.com). Two types of CESS configurations were spread at olfactory level: CESS#1 and CESS#3, a hospital smell (modification of a eucalyptus and bleach base), and CESS#2 and CESS#4, a lavender scent.

Figure 7.3 shows one of the experiences.

Figure 7.3. Participant of Phase II, during the CESS#2 experience.

3.2.5. Data processing

Psychological and neurophysiological data were recorded for each participant. iMotions (v.6.1; www.imotions.com) was used on the research PC to manage the protocol and compile the data.

Psychological data. These data were focused on measuring the participants' stress and sense of presence evoked by the experiences of the CESS. For stress metrics, a stress self-assessment and the State-Trait Anxiety Inventory were used, and, for sense of presence, a SUS questionnaire was used.

- Stress self-assessment. Assessment of stress by means of a Likert scale ranging from -2 to 2. The question 'This waiting room has caused me stress…' was used.
- State-Trait Anxiety Inventory. Test that assesses anxiety as a trait and as a state, developed by Spielberger, Gorsuch, and Lushene (1970). It consists of two inventories, one for each concept (Trait Anxiety Inventory and State Anxiety Inventory). Both contain 20 items evaluated by means of a Likert scale ranging from 1 to 4, with the outcomes being transformed into percentiles. Using the Trait Anxiety Inventory, participants under and over the 25th and 75th percentiles were excluded (one was removed) to avoid possible anomalies (Maxfield & Melnyk, 2000).
- SUS questionnaire. Presence test developed by Slater, Usoh, & Steed (1994). This measures level of presence through six items on a Likert scale ranging from 1 to 7. This assessed whether the simulations could be considered satisfactory.

Neurophysiological data. These data were used to complement the psychological data. Electrodermal, heart-rate variability, and electroencephalogram metrics related to stress were used.

- Electrodermal activity (EDA). Analysing this signal reveals its phasic component, an indicator of sympathetic activity. The EDA signal was recorded at 128 Hz using a Shimmer 3GSR+ device (www.shimmersensing.com). The raw signal was pre-processed and analysed using Ledalab (v.3.4.8, www.ledalab.de) via Matlab (v.2016a; www.mathworks.com). Pre-processing consisted of (1) Butterworth low-pass signal filtering at 2.5 Hz (Valenza & Scilingo, 2014), (2) signal downsampling to 10Hz (Lang, Zhou, Schwartz, Bolls, & Potter, 2000) and (3) visual-diagnostic of artefacts and their corrections. The CDA (Continuous Decomposition Analysis) method was used to calculate the phasic metric (Benedek & Kaernbach, 2010). Thereafter, the values were standardized following Venables & Christie (1980).

- Heart-rate variability (HRV). Analysing this signal in the frequency domain makes it possible to distinguish the ratio between low frequency to high frequency (LF/HF). This ratio is a balance indicator of sympathetic activity over parasympathetic activity (Malliani, 1999). The Electrocardiogram signal was recorded at 256 Hz using a b-Alert x10 device (www.advancedbrainmonitoring.com). It was pre-processed and analysed using HRVAS (v.2014-03-21) via Matlab. Pre-processing consisted of (1) detection of R-points by means of the Pan-Tompkins algorithm (Pan & Tompkins, 1985) and (2) visual diagnosis of ectopic beats and their corrections and the elimination of excessively noisy intervals. The analysis processed the interbeat intervals in the time-frequency domain using the Welch method and setting the frequencies of 0.05 to 0.15 Hz for LF and 0.15 to 0.4 Hz for HF (Berntson et al., 1997).
- Electroencephalogram (EEG). In order to analyse this signal, the power spectral density classification within defined frequency bands is often used. More recently, analyses of irregularity have been proposed as appropriate. Thus, the metrics used in this study were the relative power of the highbeta band (21–30 Hz) of the C3 electrode (Choi et al., 2015) and amplitude-aware permutation entropy (AAPEn of the P3 electrode; Azami & Escudero, 2016). The EEG signal was recorded at 256 Hz using a b-Alert x10 device. The raw signal was pre-processed and analysed using EEGLAB (Delorme & Makeig, 2004) via Matlab (v.2016a). The pre-processing consisted of the signal conditioning stages and artefact identification. Signal conditioning consisted of (1) EEG traces baseline removal by mean subtraction, (2) band pass filtering between 0.5 and 40 Hz (Gudmundsson, Runarsson, Sigurdsson, Eiriksdottir, & Johnsen, 2007) and (3) checking corrupted data channels, which were considered thus if the signal was flat more than 10% of the total duration or if the channel kurtosis reached a threshold of 5 standard deviations from all-channels kurtosis (Delorme, Makeig, & Sejnowski, 2001). Where there was a corrupted electrode, the data were interpolated using the neighbouring electrodes, but where more than one was corrupted, the complete record was deleted (Colomer et al., 2016). Following this, the resultant signal was divided into one-second epochs. Artefact identification involved (1) checking corrupted epochs, which were considering thus if kurtosis reached the same threshold within a single channel, (2) automated detection, rejecting epochs exceeding the threshold of 100μV or a gradient of 70.00μV between samples, and (3) independent component analysis (ICA) application (Hyvärinen & Oja, 2000), rejecting those related to an artefact. Finally, the selected metrics were calculated from the resultant signals.

The neurophysiological data were recorded at two times (Figure 7.1): during the baseline of the 'pre-experience' stage (four minutes) and during the experience of each CESS of the 'CESS-experience' stage (two minutes per CESS). The baseline was incorporated because the correlation of some neurophysiological metrics (EDA-Phasic, EEG-Hightbeta and EEG-AAPEn) was calculated using the normalized values with regard to the baseline (). In doing so, two outcomes were obtained: (1) the average of each CESS and (2) the analysis as a function of time, assigning to each second its relative value with regard to the initial second of each CESS () and, for the representation, normalizing it from 0 to 1 considering the values of all CESS.

3.2.6. Data analysis

After the database of participants' psychological and neurophysiological responses had been collected and anonymized, statistical analysis consisting of four sub-phases was carried out. IBM SPSS software was used.

- Phase IIA: Analysis of levels of presence in CESS simulations. The average sense of presence was analysed for each environmental simulation. We verified that this level was sufficient.
- Phase IIB: Analysis of stress psychological metrics and their relationships. First, the average levels of stress self-assessment and the State Anxiety Inventory for each CESS simulation were obtained. Next, the Friedman test and post hoc analysis with Wilcoxon signed-rank tests were conducted to identify any statistically significant differences between each pair of simulations. The Friedman test was used because the analysis was based on repeated measures comparisons, and the variables were not normally distributed, as per the results of the Kolmogorov-Smirnov test ($p < 0.005$). Finally, the Spearman correlation coefficient between psychological metrics was used to examine possible relationships between the two psychological metrics.
- Phase IIC: Analysis of neurophysiological metrics related to stress. As in Phase IIB, the average levels of neurophysiological metrics related to stress for each CESS simulation were first obtained. Next, the Friedman test and post hoc analysis with Wilcoxon signed-rank tests were conducted. The analysis of these metrics was complemented with a descriptive analysis as a function of time so that it was possible to graphically observe changes in the levels of stress due to the experience of the CESS over time.
- Phase IID: Relationship between the neurophysiological and psychological metrics. The Spearman non-parametric correlation coefficient was used to examine possible relationships between the psychological and neurophysiological responses.

4. Results

This section describes the results obtained in Phase I and Phase II.

4.1. Phase I

Statistical analysis of the Phase I data produced the following results.

4.1.1. Analysis of the individual effects of the environmental satisfaction sources on stress reduction

Participants' assessments of the 19 environmental satisfaction sources according to their effects on stress reduction were obtained (Figure 7.4). Five of these sources ('nice scent', 'pictures for children', 'non-intense music', 'vegetation' and 'play facilities for children') had relatively high values with respect to the others. Conversely, two sources ('space for baby buggies' and 'furniture arranged facing one another') had relatively low values. These results show the varying effects of environmental satisfaction sources on reducing the stress of fathers and mothers of child users of waiting rooms. Although the findings from this phase cannot be used as a guide for the stimuli, they suggest the directions in which efforts should be made to incorporate environmental satisfaction sources into paediatric waiting rooms. All participants reported high stress levels (X = 1.03, S = 0.978) while they were waiting to be seen. This result indicates that they were in a highly stressful situation when they assessed the environmental satisfaction sources.

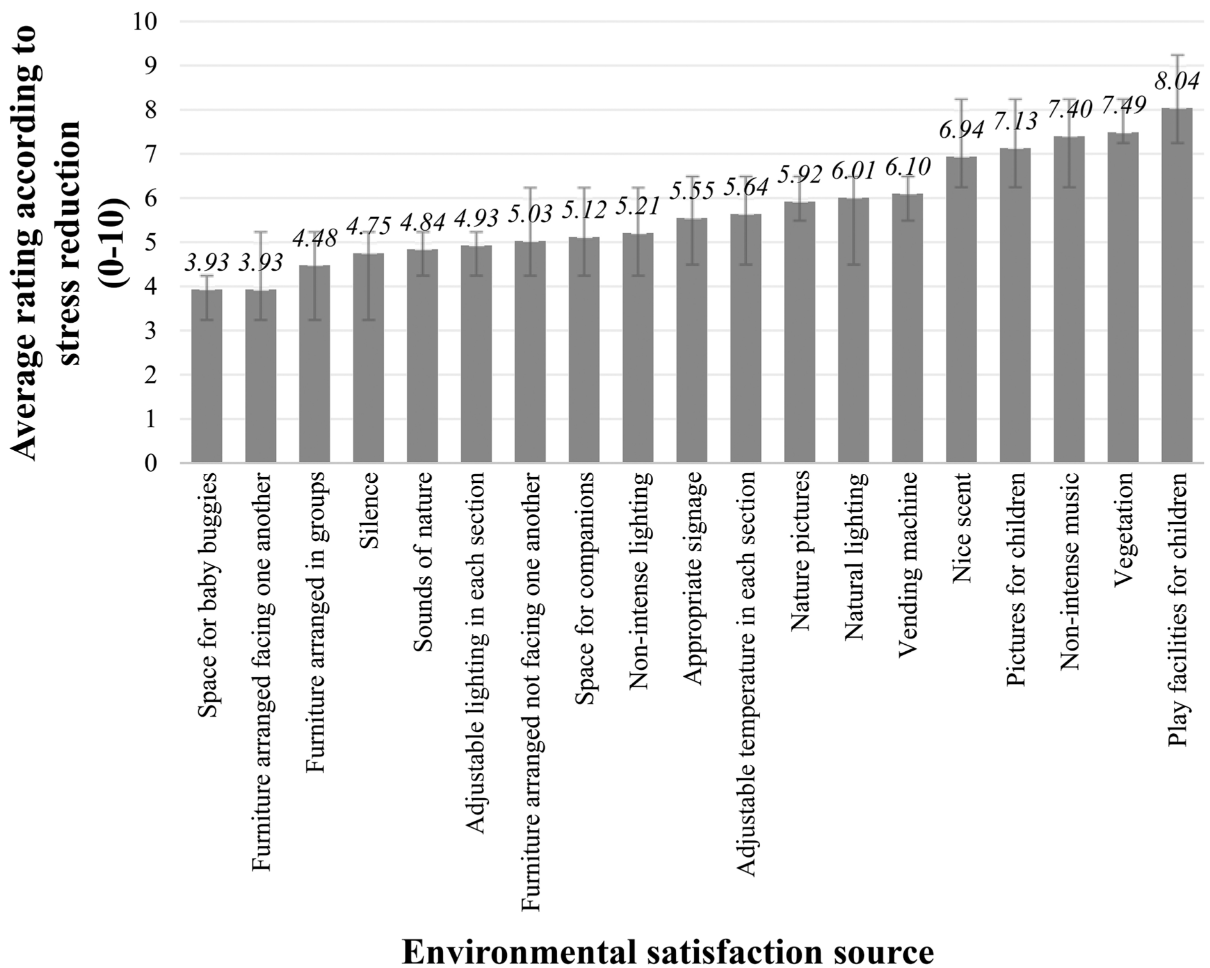


Figure 7.4. Average stress reduction ratings for the environmental satisfaction sources.

4.2. Phase II

Statistical analysis of the Phase II data produced the following results.

4.2.1. Phase IIA: Analysis of sense of presence in CESS simulations

Average levels of sense of presence per participant (according to the SUS questionnaire) for each CESS simulation were obtained (Figure 7.5). They were considered to be sufficient, taking into account the results obtained by studies using similar technologies (Slater & Steed, 2000). Thus, the simulations can be considered satisfactory.

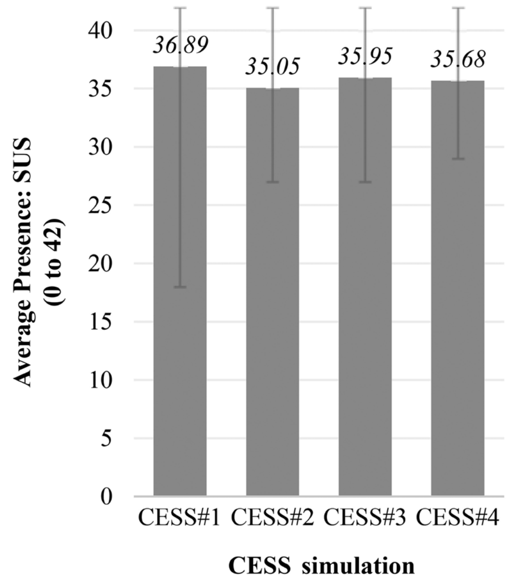


Figure 7.5. Average level of presence per participant in each CESS simulation.

4.2.2. Phase IIB: Analysis of psychological stress metrics and their relationships

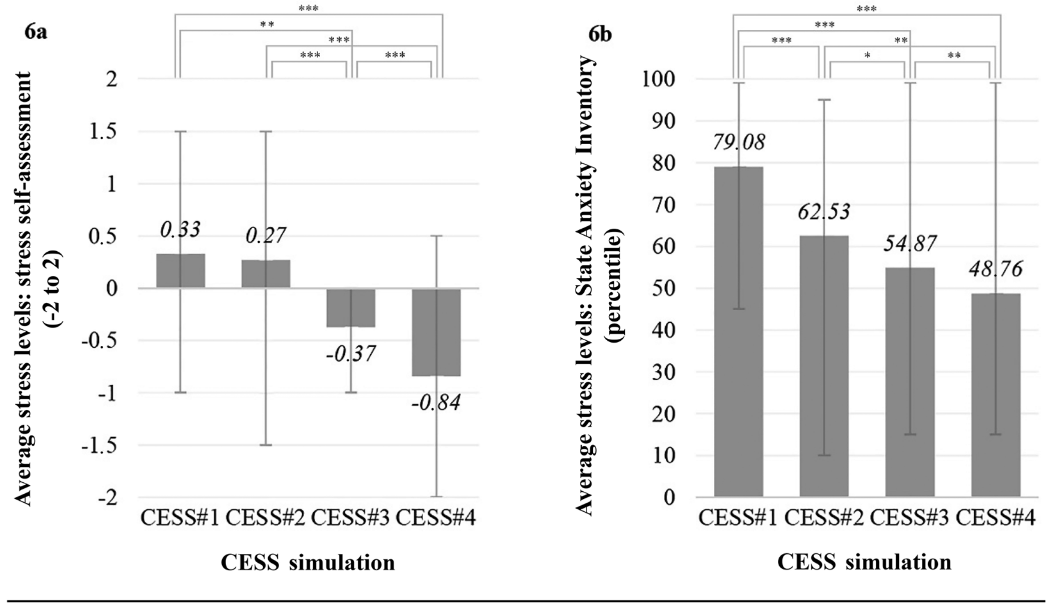
Psychological stress was measured by means of stress self-assessment and the State Anxiety Inventory. Average levels of both metrics for each CESS simulation were obtained, and significant differences were examined.

4.2.2.1. Stress self-assessment

We observe that all CESS achieve stress reduction with respect to the stress for CESS#1 (standard waiting room). CESS#3 achieves a greater reduction than CESS#2, and their combination (CESS#4) has a synergistic effect. The Friedman test indicates significant differences for the set of analysed CESS ($p = 0.000$). Post hoc analysis with Wilcoxon signed-rank tests shows that significant differences exist between all combinations except between CESS#1 and CESS#2 ($p = 0.096$; Figure 7.6a).

4.2.2.2. State Anxiety Inventory

Similar stress reduction to that quantified by the stress self-assessment is observed, even though the stress reduction for CESS#4 is less pronounced than for the others. The Friedman test shows significant differences for the set of analysed CESS ($p = 0.000$). Wilcoxon signed-rank tests show that differences exist between all combinations (Figure 7.6b).



The keys indicate the comparisons and the asterisks the significance level
*(*p < 0.05, **p < 0.01, ***p < 0.001)*

Figure 7.6. Average level of psychological stress per participant in each CESS simulation.

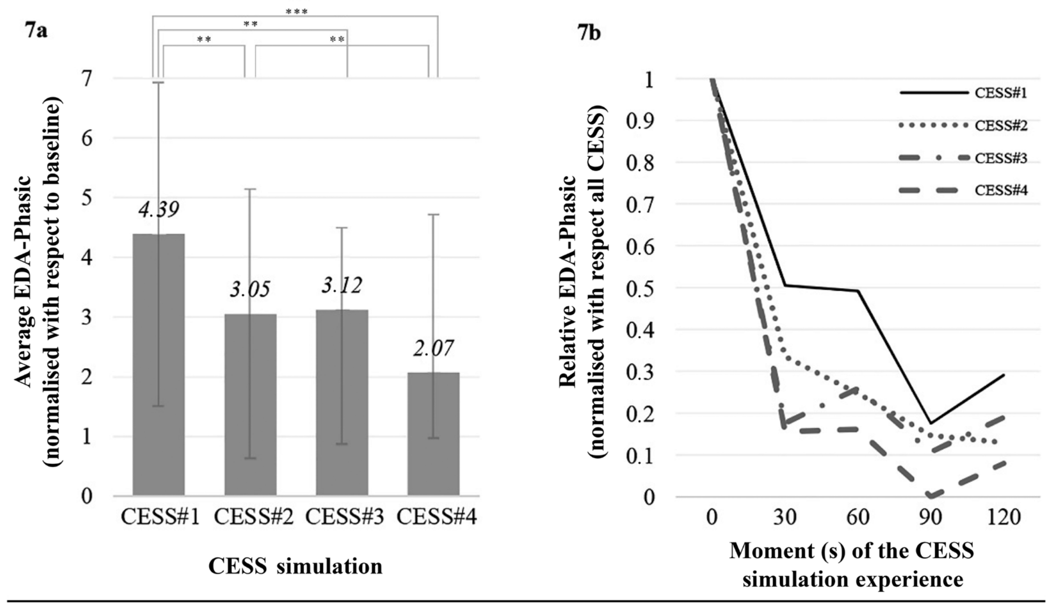
Finally, bivariate correlations were obtained between both metrics using the Spearman coefficient. This analysis shows that the two metrics are significantly related (Spearman correlation coefficient = 0.493, significance level = 0.000). Therefore, in this study, it can be argued that stress self-assessment, although less exhaustive, provides insight when quantifying the level of psychological stress.

4.3 Phase IIC: Analysis of psychological stress metrics and their relationships

Neurophysiological stress was measured by means of EDA-Phasic, HRV-LFHF, EEG-Highbeta and EEG-AAPEn metrics. The levels for each CESS simulation were obtained, and significant differences were examined. In addition, analysis as a function of time was performed.

4.3.1. EDA-Phasic

We observe that all CESS achieve a reduction in stress with respect to stress levels for CESS#1 (standard waiting room). Although this does not follow the same pattern as at the psychological level, because CESS#3 has a slightly higher average value than CESS#2, the synergistic effect of CESS#4 also appears in this metric. The Friedman test shows significant differences for the set of analysed CESS (p = 0.001). Wilcoxon signed-rank tests show that differences exist between all the CESS except between CESS#2 and CESS#3 (p = 1.000) and between CESS#3 and CESS#4 (p = 0.096; Figure 7.7a). Figure 7.7b shows the changes in this metric as a function of time. Although all CESS reduce stress levels with respect to the base position, CESS#3 and CESS#4 do so significantly quicker. It is also notable that all the CESS representations as a function of time are interrupted at approximately second 90.

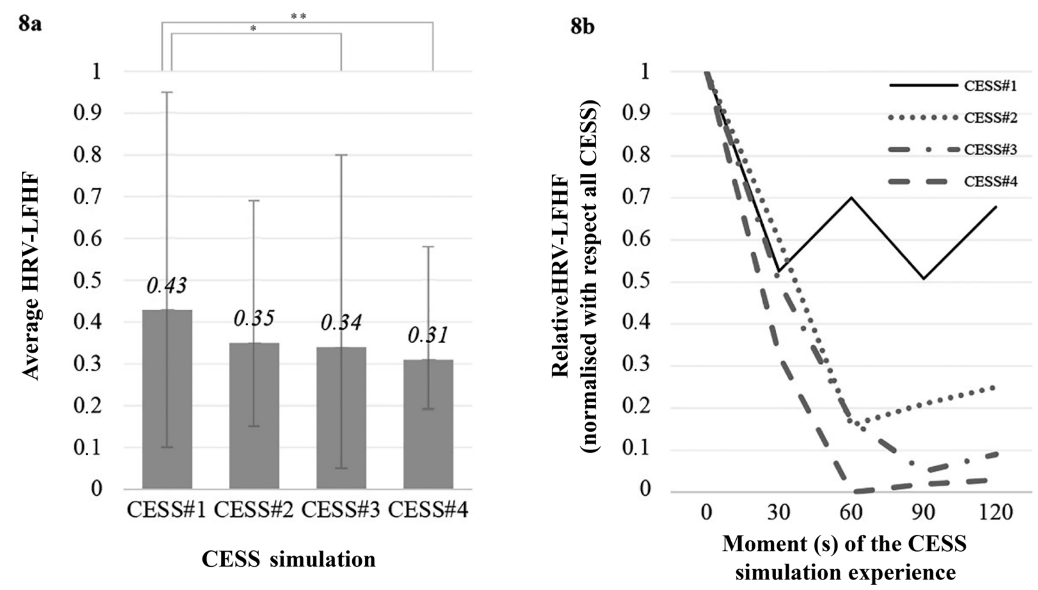


The keys indicate the comparisons and the asterisks the significance level
*(*p < 0.05, **p < 0.01, ***p < 0.001)*

Figure 7.7. Average EDA-Phasic per participant in each CESS simulation.

4.3.2. HRV-LFHF

All CESS achieve a stress reduction with respect to the stress levels for CESS#1 (standard waiting room), and CESS#4 has a synergistic effect. However, CESS#2 and CESS#3 have similar values. The Friedman test indicates that there are no significant differences for the set of analysed CESS (p = 0.494). A more specific analysis by means of Wilcoxon signed-rank tests shows that there are indeed no significant differences among the CESS, except between CESS#1 and CESS#4 (p = 0.003) and between CESS#1 and CESS#3 (p = 0.035; Figure 7.8a). Figure 7.8b shows the changes in this metric as a function of time. A notable difference is found between CESS#1 and the other CESS: This CESS does not manage to reduce stress levels from second 30 onwards, but the other configurations continue to contribute to reducing stress levels until second 60. The CESS#1 and CESS#3 representations as a function of time are interrupted at approximately second 90, similar to the previous metric.



*The keys indicate the comparisons and the asterisks the significance level (*p < 0.05, **p < 0.01, ***p < 0.001)*

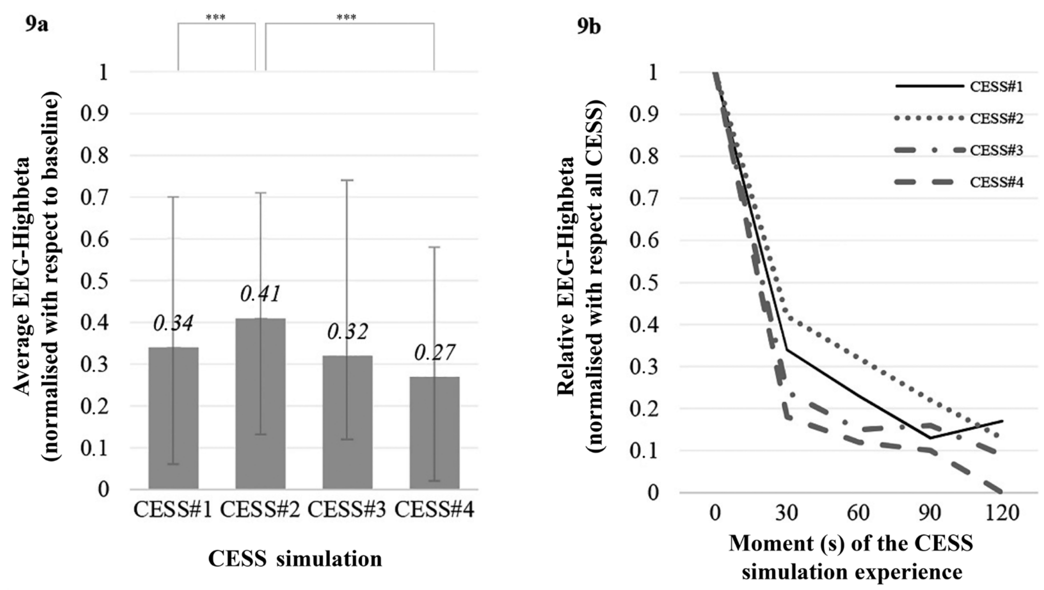
Figure 7.8. Average HRV-LFHF per participant in each CESS simulation.

4.3.3. EEG-Highbeta

This metric shows slightly different behaviour to the others. Thus, all CESS, except CESS#2, achieve stress reduction when compared to CESS#1 (standard waiting room), and the contribution of CESS#3 to reducing stress is minor. Nevertheless, the synergistic effect of CESS#4 coincides with the previous metrics. The Friedman test indicates significant differences for the set of analysed CESS (p = 0.000). Wilcoxon signed-rank tests show these differences between CESS#1 and CESS#2 (p = 0.000) and between CESS#2 and CESS#4 (p = 0.000; Figure 7.9a). Figure 7.9b shows the changes in this metric as a function of time. Although CESS#2 has average values that are higher than those of CESS#1, CESS#2 has a greater reduction in the final period. Perhaps a more prolonged exposure to the configurations would improve its overall values. Furthermore, the strong similarity between the patterns of CESS#1 and CESS#2 reveals that the environmental satisfaction sources of CESS#3 might function in a different way. The CESS#1 representations as a function of time are also interrupted at approximately second 90.

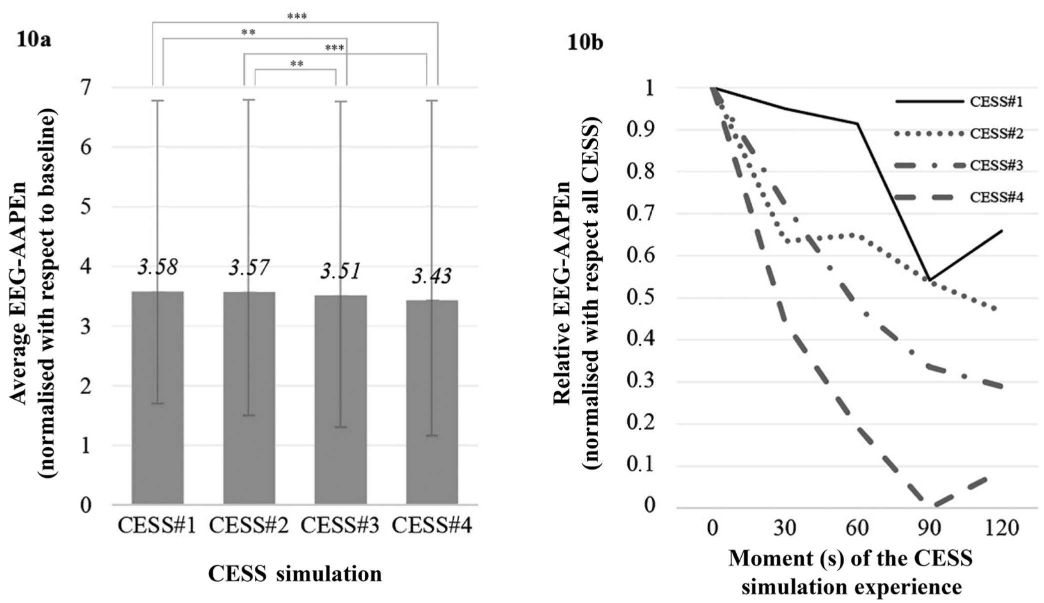
4.3.4. EEG-AAPEn

All CESS achieve stress reduction with respect to the stress levels for CESS#1 (standard waiting room), and CESS#4 has a synergistic effect. However, the reduction in CESS#2 is marginal, with an average value that is very similar to the value for CESS#1. The Friedman test shows significant differences for the set of analysed CESS (p = 0.005). Wilcoxon signed-rank tests show that these differences exist between CESS#1 and CESS#3 (p = 0.007), CESS#1 and CESS#4 (p = 0.000), CESS#2 and CESS#3 (p = 0.010) and CESS#2 and CESS#4 (p = 0.001; Figure 7.10a). Figure 7.10b shows the changes in this metric as a function of time. CESS#3 and CESS#4, although different in their average values, follow a constant tendency in the reduction of stress levels (in contrast to CESS#1 and CESS#2, which experience greater disruptions). All CESS except CESS#2 are interrupted at approximately second 90.



*The keys indicate the comparisons and the asterisks the significance level (*p < 0.05, **p < 0.01, ***p < 0.001)*

Figure 7.9. Average EEG-Highbeta per participant in each CESS simulation.



*The keys indicate the comparisons and the asterisks the significance level (*p < 0.05, **p < 0.01, ***p < 0.001)*

Figure 7.10. Average EEG-AAPEn per participant in each CESS simulation.

4.4. Phase IID: Relationship between neurophysiological and psychological metrics

Bivariate correlations between the neurophysiological and psychological metrics were obtained. The Spearman non-parametric correlation coefficient was used with a significance level of $p < 0.05$. Analysis shows stronger correlations between the stress self-assessment and the neurophysiological metrics. Thus, EDA-Phasic, EEG-Highbeta, and EEG-AAPEn metrics have a significant positive correlation with the psychological metric, which, in the case of the last EEG metric, is also applicable to the State Anxiety Inventory. There is no correlation between HRV-LFHF and the psychological metrics. Table 7.3 shows the results.

Table 7.3. Correlations between the neurophysiological and psychological metrics.

		Stress self-assessment	State Anxiety Inventory
EDA-Phasic	Spearman correlation coefficient	.547**	.034
	Significance level	.000	.790
HRV-LFHF	Spearman correlation coefficient	-.056	-.047
	Significance level	.405	.481
EEG-Highbeta	Spearman correlation coefficient	.229*	.102
	Significance level	.002	.175
EEG-AAPEn	Spearman correlation coefficient	.479**	.316**
	Significance level	.000	.000

5. Discussion

The contributions of this study relate to three areas: methodology, application and metrics to quantify stress.

At the methodological level, there are two main contributions. First, combinations of environmental satisfaction sources were studied. Although many studies tackle the improvement in the condition of patients based on specific variables, this study provides insight into their combined effect. Second, neurophysiological measures were used to quantify stress. This allowed us to explore factors related to unconscious processes.

At the application level, our findings have two important implications: (1) stress reduction in children's companions and (2) the effect of environmental satisfaction sources based on sensory modality.

With regard to stress reduction, we suggest that it is possible to use environmental satisfaction sources to reduce the stress levels of children's companions. This result is in line with those reported by Ulrich (1991) and Kjellgren and Buhrkall (2010). We show that, with respect to the stress of the standard waiting room, stress reduction due to all combinations of environmental satisfaction sources is evident at the psychological and neurophysiological levels. The EEG-Highbeta metric offers the only contradictory result, which even differs from the other EEG metric (AAPEn). The effect of environmental satisfaction sources on stress reduction is different depending on their sensory modality. The greatest effect is achieved through the combination of visual, auditory and olfactory sources (CESS#4), with high synergy at the psychological and neurophysiological levels. The importance of this result is that no similar experiment has been carried out previously. At the level of specific stimuli, the selected ambient environment features (CESS#3) produce a greater effect than the interior design features (CESS#2), especially on a psychological level. This result is interesting because hospitals generally focus on visual environmental satisfaction sources (Nanda et al., 2012), ignoring other stimuli that can significantly reduce stress.

At the level of use of the psychological and neurophysiological metrics, three aspects should be discussed: (1) the choice of psychological metrics, (2) the choice of neurophysiological metrics and (3) the interruption of the representations of the metrics as a function of time.

As to the choice of psychological metrics, stress self-assessment may have advantages. It strongly correlates with the State Anxiety Inventory, and, contrary to this metric, correlates with most neurophysiological metrics. Despite being less exhaustive than the inventories developed for stress assessment (Tennant & Andrews, 1976), the stress self-assessment is faster to administer. This is advantageous if the experimental phase is prolonged or HMD devices are used, because its resolution makes it difficult to read. Consequently, stress self-assessment is a tool that should be considered in studies that follow a similar methodology.

As to the neurophysiological metrics, all seem appropriate, with the exception of HRV-LFHF. This is the only neurophysiological metric that does not correlate with either of the two psychological metrics. This result supports other studies showing that HRV-LFHF is insufficient to measure the sympathovagal balance (Billman, 2013). Conversely, EEG-AAPEn correlates more strongly with the two psychological metrics than the other neurophysiological metrics. It should be noted that EEG-AAPEn has been identified as a powerful tool for the identification of stress by means of EEG (García-Martínez, Martínez-Rodrigo, Zangróniz, Pastor, & Alcaraz, 2017). The correlations of EDA-Phasic and EEG-Highbeta with stress are in line with the classic literature. Moreover, neurophysiological metrics enable analysis as a function of time. It has been found that auditory and olfactory environmental satisfaction sources reduce stress levels quicker than visual sources; this finding is consistent with studies that discuss their potential (Diego et al., 1998). In general, neurophysiological metrics confirm their validity for quantifying stress in virtual simulations. However, this study only considers a selection of neurophysiological metrics that were deemed appropriate based on the literature review. Future research could benefit from adding others that have also been linked to stress – such as the SD/rMSSD ratio in HRV (Sollers, Buchanan, Mowrer, Hill, & Thayer, 2007) and the nSRR in EDA (Blechert, Lajtman, Michael, Margraf, Wilhelm, 2006) – as well as neurophysiological records of a different nature – such as pupillometry (Pedrotti et al., 2014). Adding these metrics could provide a more exhaustive study.

In terms of the disruption of the tendency in the neurophysiological metrics, it is hypothesized that this is due to the fatigue effect generated by the technology employed. This occurs with all neurophysiological metrics around second 60 for HRV-LFHF and second 90 for the others. Virtual reality may provoke different symptoms and effects, among which is an increase in arousal (Cobb, Nichols, Ramsey, & Wilson, 1999). This effect may increase depending on the device employed, such as HMDs. Moreover, studies using similar set-ups have found comparable effects, although these effects were not specified in terms of time (Felnhofer et al., 2015). Thus, because there seems to be a notable negative effect after 90 seconds, exceeding this point may not be appropriate given the objective of the study. This effect could have conditioned the stress levels, but the period of adaptation to the virtual reality set-up and the counterbalancing design of the CESS experiences would have minimized the effects of the experience of the experiment for comparison purposes. Specific studies should be carried out in the future to evaluate this effect in detail, although it is likely to disappear as environmental simulation technologies improve.

Some limitations of the study must be taken into account, particularly when extrapolating the results to other contexts. First, the results are focused on a paediatric service waiting room, and the participants were companions. It is possible that the results may vary as a consequence of repeating the study in a different space and with different participant profiles. In terms of space, the environmental satisfaction sources should be adapted to the different health centre services. Regarding participant profiles, divergences may exist because of different origins of stress in staff (Gray-Toft & Anderson, 1981) and patients (Jessee et al., 2000). Thus, future studies could consider all profiles to establish common strategies within the same service. Second, the waiting room that was used as the standard is representative of Spanish waiting rooms, with the same colours, smells and sounds. It is possible that the results would differ if the research was repeated in another country. Thus, in order to recreate this study, different samples and locations should be used.

6. Conclusions

This research examines the effect that certain paediatric service waiting room configurations have on companions' stress levels. The results suggest that a combination of multisensory environmental satisfaction sources produce a synergistic effect measurable at the psychological and neurophysiological levels. By studying them in terms of sensory modality, we observe that there is greater stress reduction through auditory and olfactory means than through visual means. Our methodological contribution is twofold: (1) simultaneous measurement of the participants' psychometric and neurophysiological responses and (2) analysis of the environmental satisfaction sources both in an isolated and combined way. The conclusions of this study may be of interest for a wide audience, including virtual reality scholars and professionals involved in the design and management of health centres. For research that focuses on or uses virtual reality as a tool, this study indicates that there may be a period (of 60–90 seconds) after which, with the technology used, an increase in arousal is generated. This may be a limitation in certain studies. For design and management, particularly of the paediatric service, this study offers findings that may be useful. In terms of design and construction, this study offers strategies to address the design of these spaces, and, in terms of management, the study provides empirical evidence of the importance of certain actions to reduce the stress levels of the users of these services. In short, this study can be useful for professionals seeking to study or reduce the stress levels of health centre users as well as those who use similar tools for other purposes.

08 Discusión

Este capítulo expone una interpretación de asuntos complementarios a los recogidos en el cuerpo principal de la Tesis Doctoral, los cuales quedan pormenorizados en los artículos de los capítulos 3 a 7. Contiene tres apartados: 1) Uso actual y limitaciones de las simulaciones ambientales en arquitectura; 2) Limitaciones de las aproximaciones a la dimensión cognitivo-emocional de la arquitectura; y 3) Más allá del estado del arte: los desafíos de la neuroarquitectura. Todos han sido adelantados en el SO1, pero aquí se presentan contextualizados con el resto de sub-objetivos: el primer apartado está especialmente relacionado con los sub-objetivos SO1 y SO2, y el segundo con los sub-objetivos SO3 y SO4. Por tanto, se trata de una discusión integrada.

1. Uso actual y limitaciones de las simulaciones ambientales en arquitectura

La arquitectura, en general, se comparte. En muy rara ocasión podría ser diseñada y construida sólo para uso del artífice. El proyecto arquitectónico es un proceso comunicado (Morris, 1963). En circunstancias usuales, la práctica incluye fases que son llevadas a cabo por uno o varios proyectistas (de manera más o menos hermética) y fases en las que se intercambian ideas con otros individuos (por ejemplo, el usuario último). Alternancia de fases que, además, puede repetirse en varias ocasiones (Powell, 1987). Ocurre de manera análoga en la enseñanza. De forma que, aun suponiendo que la dimensión cognitivo-emocional de la arquitectura sea abordada desde la amalgama de prácticas y motivaciones propias del proceso proyectual, entre las que se incluye la intuición, en determinados momentos resulta ineludible intercambiar información sobre esta dimensión. Así, el proyecto de arquitectura es un asunto de diseño y, en ocasiones, puede serlo de psicología ambiental.

Esto implica que, a la hora de elegir sistema de simulación, deben atenderse los criterios propios de ambos contextos. Validez y credibilidad. Como se comentó previamente: la validez (la capacidad de una simulación para evocar en el usuario una respuesta similar a la del entorno físico representado) está más relacionada con la psicología ambiental; y la credibilidad (la calidad percibida de la representación) está más relacionada con el diseño. En la presente Tesis Doctoral se exploró el concepto de validez, a través del SO2; y el concepto de credibilidad, a través del SO3.

Como consecuencia, los avances tecnológicos que involucran ambos criterios también tienen un efecto significativo en la práctica arquitectónica. Al respecto, los sistemas basados en realidad virtual están incorporando numerosos desarrollos. Los principales se refieren a dos grandes vías: los relativos al entorno; y los relativos al sistema. En cuanto a la vía relativa al entorno, el constante desarrollo de motores de realidad virtual hace factible predecir que, a medio plazo, será posible generar escenarios fotorrealistas a tiempo real. Muchos de los algoritmos de elaboración de entornos tenían un coste de computación inabordable, y hoy en día pueden desarrollarse a tiempo real utilizando equipos no profesionales (Burgess, 2020). De hecho, en ocasiones ya es difícil diferenciar entre entorno físico y representado. En cuanto a la vía relativa al sistema, pueden mencionarse diferentes factores. Entre ellos: la resolución, la inmersión, y la interactividad. El aumento de la resolución es un esfuerzo constante desde los inicios de la realidad virtual; sobre todo en los soportes inmersivos, en los que resulta necesario disponer de pantallas portátiles de alto desempeño. Algo que hace pocas décadas era imposible técnicamente. Hoy, el desarrollo ha llevado a los soportes inmersivos actuales, que ofrecen alrededor de 3000x1500 pixeles y se mejoran cada pocos años; por lo que la tecnología está próxima a ofrecer una experiencia visual similar a la física (Deering, 1998). El factor inmersión tampoco resulta problemático actualmente. Los soportes ofrecen un elevado aislamiento de la realidad física que rodea al usuario, sobre todo a nivel visual. Además, aunque parte del peso del equipo que soporta el usuario para hacer posible este aislamiento está más lejos de solucionarse, los soportes inalámbricos (la mayoría están conectados al ordenador mediante cableado) han supuesto un avance substancial (Kim & Yun, 2020). La proyección técnica parece indicar que los factores relativos a la resolución y a la inmersión serán solventados a medio plazo. Colateralmente, este previsible avance tecnológico solucionará la dificultad actual de trabajar simultáneamente con sistemas de simulación inmersivos y dispositivos de electroencefalograma. Sin embargo, el factor interactividad es crítico y no está resuelto. Más aun teniendo en cuenta que es clave para la realidad virtual (Rheingold, 1991). De hecho, la navegación en los entornos virtuales es connaturalmente más pobre que en los entornos físicos (Richardson et al., 1999; van der Ham et al., 2015) y no existe consenso sobre cuál de las distintas metáforas empleadas para navegación (físicas o a través de dispositivos como los *joysticks*) es más apropiada (Lee, Ahn, & Hwang, 2018). Con todo, ambas vías, la relativa al entorno y la relativa al sistema, tienen importancia en el diseño y estudio de la dimensión cognitivo-emocional de la arquitectura. No obstante, hay una robusta comunidad académica y profesional enfrentando este desafío. Además, los resultados obtenidos para abordar el SO2 y el SO3 sugieren una elevada utilidad de los nuevos formatos (en específico, la realidad virtual y los panoramas 360º) y soportes (en específico, los HMD).

2. Limitaciones de las aproximaciones a la dimensión cognitivo-emocional de la arquitectura

El estudio de la dimensión cognitivo-emocional de la arquitectura es complejo. En la presente Tesis Doctoral, el SO1 examinó a nivel teórico cómo las aproximaciones nuevas están ayudando a superar las limitaciones de las aproximaciones tradicionales (relativas a los estímulos y las evaluaciones) y a identificar directrices de diseño centradas en apoyar las necesidades de esta dimensión. A nivel práctico, a través del SO4 se exploró la combinación de metodologías cuantitativas y cualitativas propias de las aproximaciones tradicionales; y a través del SO5 se exploró el uso conjunto de registro neurofisiológico y de realidad virtual (cuya utilidad fue estudiada en los SO2 y SO3). Sin embargo, ninguna de las aproximaciones está exenta de limitaciones. A continuación, en línea con el análisis del artículo que aborda el SO1, se examinan las limitaciones generales que presenta el conjunto de aproximaciones y se ponen en contexto con lo ejecutado en los artículos que abordan los demás sub-objetivos.

2.1. Limitaciones a nivel ontológico

A nivel ontológico, las limitaciones se derivan de la complejidad de la experiencia arquitectónica. Destacan cuatro argumentos: 1) la modalidad de los estímulos; 2) la temporalidad de los estímulos: 3) los aspectos estudiados; y 4) la universalidad de la experiencia. El primer argumento (modalidad de los estímulos) se refiere a que, en general, los estudios utilizan análisis sensoriales unimodales. En concreto, centrados en la vista (Skov, 2009). Aunque la mayor parte de la información que procesamos es de este tipo (Bourdieu, 1989; Bruce et al., 2003), la arquitectura involucra todas las modalidades sensoriales (Mehta, 2014; Papale et al., 2016). Por lo tanto, las experiencias unimodales visuales (y por extensión las investigaciones basadas en éstas) no retratan la complejidad de la experiencia arquitectónica (Ebrahem, 2018; O'Neill, 2001). El segundo argumento (temporalidad de los estímulos) se refiere a que la arquitectura es un continuo experiencial (Holl, 2011). La transición de un espacio a otro puede condicionar la experiencia arquitectónica (Djebbara, 2018), por lo que los estímulos usualmente empleados en investigación (descontextualizados, discretos y estáticos; por razones metodológicas) podrían estar de alguna forma sesgados. El tercer argumento (aspectos estudiados) se refiere a la tendencia de la bibliografía a estudiar la belleza. Aunque la arquitectura es una de las "Bellas Artes" (Batteux, 1746), la experiencia estética es sólo uno de los componentes de la dimensión cognitivo-emocional de la arquitectura. Por lo tanto, no es suficiente para describirla (Brown & Dissanayake, 2009). La arquitectura trata de satisfacer necesidades cognitivas-emocionales más amplias (Andreasen, 1985). Además, pueden existir grandes obras no caracterizadas por la belleza (Richter & Britt, 1997). El cuarto argumento (universalidad de la experiencia) se refiere al debate tangente sobre la universalidad del arte (Dutton, 2009; Trehub, 2000). El punto clave es que el cerebro se adapta al entorno (Rakic, 2002), proceso que se conoce como "neuroplasticidad" (Livingston, 1966). Así, la experiencia arquitectónica está condicionada por factores biológicos y ambientales (Kozbelt, 2017); teniendo estos últimos un efecto substancial (Whitfield, 1984). Por lo que es muy probable que sea imposible alcanzar un diseño arquitectónico universal. De hecho, hay menos consenso a la hora de juzgar artefactos que elementos naturales (Vessel et al., 2018). No obstante, dado que todos los seres humanos presentamos cerebros innatamente similares (Cupchik et al., 1992; Swaab, 2014), existen razones para pensar que las directrices de diseño identificadas a través de investigaciones como las de la presente Tesis Doctoral al abordar el SO4 y el SO5, pueden tener un amplio alcance. Con todo, estas cuestiones van en contra de la fragmentación de la experiencia arquitectónica, e incentivan la tradicional tendencia a los casos de estudio (Jones & Canniffe, 2007). En este sentido, la experimentación desarrollada para abordar el SO5 se esforzó en sortear las tres limitaciones ontológicas: los estímulos fueron multimodales (abarcaron la vista, el oído, y el olfato), estuvieron contextualizados (de manera previa a la experiencia arquitectónica, los usuarios eran puestos en escena y temporalmente expuestos a una situación demandante), y los aspectos estudiados no se limitaron a la belleza (se cuantificó el estrés psicológica y neurofisiológicamente a través de varios cuestionarios y métricas).

2.2. Limitaciones a nivel epistemológico

A nivel epistemológico, la limitación fundamental deriva de la dificultad de explicar la experiencia arquitectónica en términos exclusivamente fisiológicos. Este argumento se refiere a la relación neurofisiología-experiencia. Dado que una zona del cerebro puede estar relacionada con varios procesos (Poldrack, 2006), existe el riesgo de hacer inferencias que no sean válidas. Al respecto, los procesos cognitivo-emocionales son especialmente complejos (Cacioppo et al., 2000). La experiencia arquitectónica puede parecer simple porque estamos habituados a ella, pero no lo es a nivel neurofisiológico. En este sentido, la experimentación desarrollada para abordar el SO4 trató de explorar la dimensión cognitivo-emocional cuantitativa y cualitativamente sin registros neurofisiológicos.

2.3. Limitaciones a nivel metodológico

A nivel metodológico, las limitaciones derivan de las circunstancias especialmente abiertas en que el usuario tiene la experiencia arquitectónica en condiciones naturales. Destacan dos argumentos: 1) procedimentales; y 2) técnicos. El primer grupo de argumentos (procedimentales) se refiere a varias razones. Por un lado, la lógica *ceteris paribus* usualmente empleada en experimentación (mediante la cual se mantienen igual todas las variables de los estímulos, a excepción de aquella que se va a estudiar controladamente) suele obligar a sacrificar la complejidad de los estímulos (Jacobsen, 2010). Algo que, como se ha visto, en arquitectura es especialmente crítico teniendo en cuenta su complejidad experiencial. Como consecuencia, la mayoría de variables no sólo no han podido ser exploradas exhaustivamente de manera aislada, sino tampoco en combinación con otras variables. Por otro lado, no todos los procesos cognitivo-emocionales implicados en la experiencia ocurren simultáneamente (Winkielman & Cacioppo, 2001), lo que puede desarticular la asignación de los registros (neurofisiológicos o comportamentales) de estos procesos a las tareas o eventos que experimentan los usuarios. Por ejemplo, la reacción de un usuario ante un estímulo auditivo puede quedar registrado en la EDA pasados unos milisegundos; y no instantáneamente. Así, sincronizar los registros neurofisiológicos con los eventos vividos o realizados por el usuario es un reto que, en determinados estudios, puede ser crítico. En relación a las tareas cabe mencionar, además, que éstas podrían llegar a desvirtuar las respuestas de los usuarios. En particular, completar un auto-reporte sobre cuestiones cognitivo-emocionales podría afectar a las propias respuestas cognitivas-emocionales (Di Dio et al., 2007): por ejemplo, el propio hecho de cuantificar el nivel de estrés podría alterar este mismo. El segundo grupo de argumentos (técnicos) se refiere a las restricciones impuestas por las herramientas de neuroimagen. A la hora de incorporarlas, éstas deben tenerse en cuenta junto a sus virtudes (Cela-Conde et al., 2011). Un ejemplo evidente es el uso del fMRI: aunque permite detectar la activación neuronal de zonas profundas del cerebro, requiere que el usuario permanezca inmóvil dentro de la máquina; lo que en el caso de estímulos arquitectónicos es especialmente restrictivo. Por consiguiente, no siempre es fácil extrapolar los resultados a una aplicación práctica. No obstante, en parte esto hoy puede solventarse con los sistemas de medición neurofisiológica portátiles (Lindquist et al., 2014), como los empleados para abordar el SO5.

3. Más allá del estado del arte: los desafíos de la neuroarquitectura

Hasta ahora, no ha habido un estudio general de las bases que subyacen a la dimensión cognitivo-emocional en el caso concreto de la arquitectura. La neuroarquitectura puede contribuir en el avance de esta cuestión y en el camino hacia una arquitectura mejor para el ser humano. Una arquitectura que apoye explícitamente a la dimensión emocional (Pallasmaa et al., 2013). Sin caer en el reduccionismo de considerar que ésta debe aspirar exclusivamente a generar niveles bajos de activación (Ruggles, 2017), ya que la dimensión cognitivo-emocional tiene mucho más que ofrecer. Como Lynch se refería a ello: podemos adaptar el medio ambiente a la pauta perceptiva (Lynch, 2008). Objetivo que puede formar parte de muchas perspectivas distintas. Desde la postulación clásica de Vitruvio (2016) –entendiendo la emoción en la arquitectura desde un sentido amplio, satisfaría los principios de "vetustas" y de "utilitas"–, hasta el énfasis contemporáneo en la sostenibilidad –que también incorpora una dimensión social– (Eberhard, 2012). Los ejemplos son tan variados como los espacios. Entre otras: hospitales que contribuyan a la curación de los pacientes (Sternberg, 2009); aulas que apoyen los procesos cognitivos de los estudiantes (Turk et al., 2018); entornos de trabajo que fomenten la colaboración entre trabajadores (Goldstein, 2006); museos adaptados perceptualmente a las obras que alberguen (Babiloni et al., 2014); restaurantes que potencien la experiencia gastronómica (Auvray & Spence, 2008); e incluso intervenciones a escala urbana (Hollander & Foster, 2016; Mavros et al., 2016; Portugali, 2004; Taylor-Hochberg, 2018), en las que uno de los retos reside en la diversidad de grupos a los que debe satisfacer. En la dirección opuesta, el diseño para colectivos específicos (entre ellos, los desfavorecidos), o incluso familias concretas, supone un enfrentamiento frontal con el diseño de masas actual. En este camino, el éxito de la neuroarquitectura dependerá, en parte, de la capacidad de las herramientas en que se basa (fundamentalmente, las de la neurociencia y la simulación ambiental) para superar sus desafíos inherentes.

No obstante, los humanos no sólo somos seres neurológicos. Por lo que, como se ha examinado con el SO1, no es sorprendente que la dimensión cognitivo-emocional de la arquitectura pueda ser abordada meritoriamente desde aproximaciones tan diferentes. De hecho, una de las contribuciones principales del artículo que aborda este sub-objetivo, es presentar la neuroarquitectura contextualizada junto a las aproximaciones precursoras. Así, la poliédrica naturaleza de la dimensión cognitivo-emocional de la arquitectura implica que el estudio general de las bases subyacentes no podría venir dado de una sola aproximación. Así, aunque la neuroarquitectura puede ayudar a estudiar la experiencia arquitectónica, no contiene todas las respuestas. De hecho, la neurociencia es más afín a responder asuntos relacionados con el "cómo" que el "porqué" (Massey, 2009). Además, como se ha comentado, a nivel práctico la dimensión cognitivo-emocional de la arquitectura ha sido tradicionalmente abordada a través de las comentadas *designerly ways of knowing*; y las distintas aproximaciones científicas (ya sea de las aproximaciones tradicionales o de las aproximaciones nuevas) rara vez son empleadas. Así pues, debe prestarse atención tanto a las bases como a la ejecución. "Los científicos y los artistas necesitan identificar un terreno común" (Pepperell, 2018). Sólo así será posible desarrollar el amplio y profundo conocimiento necesario para generar una verdadera herramienta de diseño que contribuya al fin último de mejorar la arquitectura.

08 Discussion

This chapter presents an interpretation of issues complementary to those covered in the main body of the Doctoral Thesis, which are detailed in the journal papers contained in chapters 3 to 7. It contains three sections: 1) Current use and limitations of environmental simulations in architecture; 2) Limitations of approaches to the cognitive-emotional dimension of architecture; and 3) Beyond the state of the art: the challenges of neuroarchitecture. All have been advanced in SO1, but here they are presented contextualised with the rest of the sub-objectives: the first section is especially related to sub-objectives SO1 and SO2, and the second to sub-objectives SO3 and SO4. It is therefore an integrated discussion.

1. Current use and limitations of environmental simulations in architecture

Architecture is generally shared. On very rare occasions it could be designed and built only for the use of the architect. The architectural project is a communicated process (Morris, 1963). In broad circumstances, the practice includes phases that are carried out by one or several designers (in a more or less hermetic manner) and phases in which ideas are exchanged with other individuals (for example, the ultimate user). This alternation of phases can be repeated several times (Powell, 1987). It happens in a similar way in teaching. So, even assuming that the cognitive-emotional dimension of architecture is approached from the amalgam of practices and motivations inherent to the design process, including intuition, at certain moments it is unavoidable to exchange information on this dimension. Thus, the architectural project is a matter of design and, on occasions, it can be a matter of environmental psychology.

This implies that, when choosing a simulation system, criteria specific to both contexts must be taken into account. Validity and credibility. As previously mentioned: validity (the ability of a simulation to evoke in the user a response similar to that of the physical environment represented) is more related to environmental psychology; and credibility (the perceived quality of the representation) is more related to design. In this Doctoral Thesis, the concept of validity was explored through SO2 and the concept of credibility through SO3.

As a consequence, technological advances involving both criteria also have a significant effect on architectural practice. In this respect, virtual reality-based systems are incorporating numerous developments. The main ones relate to two main directions: those related to the environment; and those related to the system. With regard to the environment, the constant development of virtual reality engines makes it feasible to predict that, in the medium term, it will be possible to generate photorealistic scenarios in real time. Many of the algorithms for environment development were computationally unaffordable, and can now be developed in real time using non-professional equipment (Burgess, 2020). In fact, it is sometimes already difficult to differentiate between physical and rendered environments. In terms of the system pathway, different factors can be mentioned. Among them: resolution, immersion, and interactivity. Increasing resolution has been a constant effort since the beginning of virtual reality, especially in immersive displays, where high-performance portable screens are necessary. This was technically impossible a few decades ago. Development has led to today's immersive displays, which offer around 3000x1500 pixels and are improved every few years, so that the technology is close to offering a visual experience similar to the physical one (Deering, 1998). The immersion factor is also not a problem today. The displays offer a high degree of isolation from the physical reality around the user, especially at the visual level. In addition, although some of the weight of the equipment that the user has to bear to enable this isolation is further away from being solved, wireless displays (most are connected to the computer by cabling) have been a substantial advance (Kim & Yun, 2020). The technical projection seems to indicate that the resolution and immersion factors will be solved in the medium term. Collaterally, this predictable technological advance will solve the current difficulty of working simultaneously with immersive simulation systems and EEG devices. However, the interactivity factor is critical and unresolved. Even more so considering that it is key to virtual reality (Rheingold, 1991). In fact, navigation in virtual environments is connaturally poorer than in physical environments (Richardson et al., 1999; van der Ham et al., 2015) and there is no consensus on which of the different metaphors used for navigation (physical or via devices such as joysticks) is more appropriate (Lee, Ahn, & Hwang, 2018). However, both environment-related and system-related directions are important in the design and study of the cognitive-emotional dimension of architecture. Nevertheless, there is a robust academic and professional community facing this challenge. Moreover, the results obtained to address SO2 and SO3 suggest a high utility of new formats (specifically, virtual reality and 360º panoramas) and displays (specifically, HMDs).

2. Limitations of approaches to the cognitive-emotional dimension of architecture

The study of the cognitive-emotional dimension of architecture is complex. In this Doctoral Thesis, SO1 examined at a theoretical level how new approaches are helping to overcome the limitations of base approaches (related to stimuli and evaluations) and to identify design guidelines focused on supporting the needs of this dimension. At a practical level, SO4 explored the combination of quantitative and qualitative methodologies of base approaches; and SO5 explored the joint use of neurophysiological recording and virtual reality (the usefulness of which was explored in SO2 and SO3). However, none of the approaches are without limitations. In the following, in line with the analysis of the journal paper addressing SO1, the general limitations of the set of approaches are examined and put in context with what has been done in the journal papers addressing the other sub-objectives.

2.1. Limitations at the ontological level

At the ontological level, the limitations derive from the complexity of the architectural experience. Four arguments stand out: 1) the modality of the stimuli; 2) the temporality of the stimuli; 3) the aspects studied; and 4) the universality of the experience. The first argument (modality of the stimuli) refers to the fact that, in general, the studies use unimodal sensory analyses. Specifically, focused on sight (Skov, 2009). Although most of the information we process is of this type (Bourdieu, 1989; Bruce et al., 2003), architecture involves all sensory modalities (Mehta, 2014; Papale et al., 2016). Therefore, unimodal visual experiences (and by extension research based on these) do not describe the complexity of architectural experience (Ebrahem, 2018; O'Neill, 2001). The second argument (temporality of stimuli) refers to architecture as an experiential continuum (Holl, 2011). The transition from one space to another can condition the architectural experience (Djebbara, 2018), so the stimuli usually employed in research (decontextualised, discrete and static; for methodological reasons) might be somewhat biased. The third argument (aspects studied) refers to the tendency of the literature to study beauty. Although architecture is one of the "Beaux Arts" (Batteux, 1746), aesthetic experience is only one of the components of the cognitive-emotional dimension of architecture. Therefore, it is not sufficient to describe it (Brown & Dissanayake, 2009). Architecture is about satisfying broader cognitive-emotional needs (Andreasen, 1985). Moreover, there can be great works that are not characterised by beauty (Richter & Britt, 1997). The fourth argument (universality of experience) refers to the tangential debate about the universality of art (Dutton, 2009; Trehub, 2000). The key point is that the brain adapts to the environment (Rakic, 2002), a process known as "neuroplasticity" (Livingston, 1966). Thus, architectural experience is conditioned by biological and environmental factors (Kozbelt, 2017); the latter having a substantial effect (Whitfield, 1984). It is therefore very likely that it is impossible to achieve a universal architectural design. In fact, there is less consensus when judging artefacts than natural elements (Vessel et al., 2018). However, given that all humans have innately similar brains (Cupchik et al., 1992; Swaab, 2014), there is reason to believe that the design guidelines identified through research such as this Doctoral Thesis in addressing SO4 and SO5 may have a broad scope. However, these issues run counter to the fragmentation of architectural experience, and encourage the traditional tendency towards case studies (Jones & Canniffe, 2007). In this sense, the experimentation developed to address SO5 strived to circumvent the three ontological constraints: the stimuli were multimodal (encompassing sight, hearing, and smell), they were contextualised (prior to the architectural experience, users were staged and temporarily exposed to a demanding situation), and the aspects studied were not limited to beauty (stress was quantified psychologically and neurophysiologically through various questionnaires and metrics).

2.2. Limitations at the epistemological level

At the epistemological level, the fundamental limitation derives from the difficulty of explaining architectural experience in exclusively physiological terms. This argument refers to the neurophysiology-experience relationship. Since one area of the brain can be related to several processes (Poldrack, 2006), there is a risk of making invalid inferences. In this respect, cognitive-emotional processes are particularly complex (Cacioppo et al., 2000). Architectural experience may seem simple because we are used to it, but it is not so at the neurophysiological level. In this sense, the experimentation developed to address SO4 tried to explore the cognitive-emotional dimension quantitatively and qualitatively without neurophysiological recordings.

2.3.Limitations at the methodological level

At the methodological level, the limitations derive from the particularly open circumstances in which the user has the architectural experience under natural conditions. Two arguments stand out: 1) procedural; and 2) technical. The first group of arguments (procedural) refers to several reasons. On the one hand, the ceteris paribus logic usually employed in experimentation (whereby all the variables of the stimuli are kept the same, except for the one that is to be studied in a controlled manner) usually forces us to sacrifice the complexity of the stimuli (Jacobsen, 2010). As we have seen, this is especially critical in architecture, given its experiential complexity. As a consequence, most variables have not only not been exhaustively explored in isolation, but also not in combination with other variables. Moreover, not all cognitive-emotional processes involved in the experience occur simultaneously (Winkielman & Cacioppo, 2001), which can disarticulate the mapping of the (neurophysiological or behavioural) registers of these processes to the tasks or events experienced by users. For example, a user's reaction to an auditory stimulus may be recorded in the EDA after a few milliseconds; not instantaneously. Thus, synchronising the neurophysiological recordings with the events experienced or performed by the user is a challenge that, in certain studies, can be critical. In relation to the tasks, it is also worth mentioning that they could distort the user's responses. In particular, completing a self-report on cognitive-emotional issues could affect the cognitive-emotional responses themselves (Di Dio et al., 2007): for example, the very act of quantifying the level of stress could alter the level of stress itself. The second group of (technical) arguments refers to the constraints imposed by neuroimaging tools. When incorporating them, these must be taken into account alongside their virtues (Cela-Conde et al., 2011). An obvious example is the use of fMRI: although it allows the detection of neural activation of deep areas of the brain, it requires the user to remain immobile within the machine; which in the case of architectural stimuli is particularly restrictive. Therefore, it is not always easy to extrapolate the results to a practical application. However, this can now be partly overcome by portable neurophysiological measurement systems (Lindquist et al., 2014), such as those used to address SO5.

3. Beyond the state of the art: the challenges of neuroarchitecture

Until now, there has been no general study of the bases underlying the cognitive-emotional dimension in the specific case of architecture. Neuroarchitecture can contribute to the progress of this issue and on the way to a better architecture for the human being. An architecture that explicitly supports the emotional dimension (Pallasmaa et al., 2013). Without falling into the reductionism of considering that it should only attempt to generate low levels of activation (Ruggles, 2017), as the cognitive-emotional dimension has much more to offer. As Lynch referred to it: we can adapt the environment to the perceptual pattern (Lynch, 2008). A goal that can be part of many different perspectives. From the classical postulation of Vitruvius (2016) - understanding emotion in architecture in a broad sense, it would satisfy the principles of "vetustas" and "utilitas" - to the contemporary emphasis on sustainability - which also incorporates a social dimension (Eberhard, 2012). The examples are as varied as the spaces. Among others: hospitals that contribute to the healing of patients (Sternberg, 2009); classrooms that support students' cognitive processes (Turk et al., 2018); work environments that foster collaboration between employees (Goldstein, 2006); museums perceptually adapted to the works they exhibit (Babiloni et al., 2014); restaurants that enhance the gastronomic experience (Auvray & Spence, 2008); and even urban-scale interventions (Hollander & Foster, 2016; Mavros et al., 2016; Portugali, 2004; Taylor-Hochberg, 2018), where one of the challenges lies in the diversity of groups to be satisfied. In the opposite direction, designing for specific groups (including the disadvantaged), or even specific families, is a direct confrontation with current mass design. On this path, the success of neuroarchitecture will depend, in part, on the ability of the tools on which it is based (primarily those of neuroscience and environmental simulation) to overcome its inherent challenges.

However, humans are not only neurological beings. So, as has been examined with SO1, it is not surprising that the cognitive-emotional dimension of architecture can be meritoriously approached from such different approaches. Indeed, one of the main contributions of the paper addressing this sub-objective is to present contextualised neuroarchitecture alongside the precursor approaches. Thus, the polyhedral nature of the cognitive-emotional dimension of architecture implies that the general study of the underlying bases could not be given from a single approach. Thus, although neuroarchitecture can help to study the architectural experience, it does not contain all the answers. In fact, neuroscience is more prone to answering questions of "how" than "why" (Massey, 2009). Moreover, as discussed, on a practical level the cognitive-emotional dimension of architecture has traditionally been addressed through the aforementioned designerly ways of knowing; and the various scientific approaches (whether base or new approaches) are rarely employed. Thus, attention must be paid to both the foundations and the execution. "Scientists and artists need to find common ground" (Pepperell, 2018). Only in this way will it be possible to develop the breadth and depth of knowledge needed to generate a true design tool that contributes to the ultimate goal of improving architecture.

09 Conclusiones

El objetivo de la presente tesis doctoral, “Neuroarquitectura: nuevas métricas para el diseño arquitectónico a través del uso de neurotecnologías”, es contribuir en la investigación y diseño de la dimensión cognitivo-emocional de la arquitectura. Esto exigió explorar cuestiones tanto teóricas como prácticas. El objetivo fue dividido en cinco sub-objetivos. El sub-objetivo SO1 examinó el estudio de la dimensión cognitivo-emocional de la arquitectura, desde una perspectiva actual que integra de manera contextualizada las aproximaciones tradicionales y nuevas. Los sub-objetivos SO2 y SO3 estudiaron la utilidad de los principales sistemas de simulación ambiental. El sub-objetivo SO4 se centró en comprobar el conocimiento que una combinación de metodologías cuantitativas y cualitativas tradicionalmente usadas puede ofrecer para estudiar la dimensión cognitivo-emocional de la arquitectura. Finalmente, el sub-objetivo SO5 examinó la potencialidad para el mismo propósito del uso conjunto de las herramientas de simulación ambiental validadas en los primeros dos sub-objetivos, junto a algunas de las metodologías evaluadas en el tercero y a sistemas de medición neurofisiológica. Así, cada uno de los sub-objetivos ofrece conocimiento sobre la respuesta humana ante situaciones concretas; que, en el caso de los SO2 y SO3, decantan en nociones para la elección de sistema de simulación ambiental; y en caso de los SO1, SO4 y SO5, en directrices de diseño. Además, en conjunto, los cinco sub-objetivos suponen una contribución metodológica de especial relevancia al no existir un marco experimental común aceptado en neuroarquitectura. Esta variedad de contribuciones, junto al marcado carácter transdisciplinar de la Tesis Doctoral, es el motivo por el cual los sub-objetivos se encuentran publicados en revistas de áreas de conocimiento diferentes. El SO1 (publicado en la revista “Sensors”), fue abordado a través de una *scoping review* (revisión de alcance) de la neuroarquitectura. Este tipo de revisiones permiten presentar una perspectiva amplia sobre cuestiones complejas en las que intervienen fuentes heterogéneas. A través de un análisis bibliográfico de 612 referencias, localizadas y consultadas durante el desarrollo de la Tesis Doctoral, el artículo traza un mapa de las distintas áreas que intervienen en la cuestión. Entre los principales resultados del artículo, se encuentran: (1) una identificación y síntesis de las principales aproximaciones tradicionales (geometría, fenomenología del espacio, geografía de la experiencia, filosofía, psicología ambiental, y *evidence based design*) y de las aproximaciones nuevas (neurociencia y realidad virtual, sobre las que además repasan sus herramientas y métodos); (2) el efecto de diferentes variables de diseño de acuerdo a las anteriores aproximaciones (lo cual es útil a nivel de desarrollo experimental, para orientar el análisis, e incluso como directrices de diseño); y (3) una discusión en cuanto al estado actual y líneas futuras sobre el estudio de la dimensión cognitiva-emocional de la arquitectura. En el caso concreto de la neuroarquitectura, esto era especialmente importante dado que suele presentarse de manera descontextualizada; lo cual genera prejuicios sobre sus posibilidades actuales y sus desarrollos futuros.

Los siguientes dos sub-objetivos abordaron la aplicación de sistemas de simulación ambiental actuales desde distintas perspectivas. El SO2 (publicado en la revista “Applied Ergonomics”), se centró en la aplicación a la psicología ambiental; y el SO3 (publicado en la revista “EGA Revista de Expresión Gráfica Arquitectónica”), en la aplicación al diseño. Al respecto de la aplicación en psicología ambiental, se encontró que los formatos panorama 360º y realidad virtual suponen un avance sobre la fotografía usual. Los entornos simulados mediante ambos formatos generan una respuesta psicológica y fisiológica más similar a la que generan los entornos físicos representados. Especialmente el panorama 360º. Al respecto de la aplicación en diseño, se trabajaron con distintos formatos y soportes. En relación a los formatos, el panorama 360º y la realidad virtual son preferidos, también, como herramienta de diseño; estando las valoraciones del primero por encima. En relación a los soportes, el HMD obtuvo mejores valoraciones que la pantalla de ordenador (a pesar de ser más familiar para la mayoría de usuarios). En general, estos resultados indican una mayor capacidad de los nuevos formatos y soportes, tanto para trabajos que estudien la respuesta cognitivo-emocional de los usuarios a través de entornos simulados (similares a lo abordado en el SO5) como para apoyar el proceso de diseño. Esta ventaja para el diseño, a pesar de que cada vez más software profesional es compatible, aún no ha decantado en una adopción general. Sin embargo, en el ámbito de la psicología ambiental encontramos un número creciente de artículos publicados que utilizan estos sistemas.

Los últimos dos sub-objetivos, de los cinco que componen el cuerpo principal de la Tesis Doctoral, abordaron el uso de distintas aproximaciones a la dimensión cognitivo-emocional de la arquitectura. El SO4 (publicado en la revista "HERD: Health Environments Research & Design Journal"), se centró en combinar metodologías cuantitativas y cualitativas de las aproximaciones tradicionales; y el SO5 (publicado en la revista "Building Research & Information"), en el uso de nuevos sistemas de simulación ambiental junto a medición neurofisiológica y psicológica. Al respecto de la combinación de metodologías tradicionales, ésta permitió identificar el conjunto de factores emocionales y la estructura conceptual detrás de las evaluaciones que los usuarios hacen del espacio. Por un lado, el uso de *focus group* resulta apropiado para dos fines: inspeccionar información sobre las necesidades de los usuarios, y recopilar los conceptos relativos a la experiencia afectiva-emocional de un espacio concreto. Por otro lado, la semántica diferencial permite extraer la estructura conceptual subyacente a los anteriores conceptos (que, si son obtenidos de otra fuente, pueden no ser representativos del usuario). Al respecto del uso de nuevas herramientas, la simulación ambiental visual (a través de panoramas 360º mostrados en HMD) auditiva (a través de auriculares) y olfativa (a través de dispensadores de fragancia), resulta compatible con el registro neurofisiológico (EEG, HRV, y EDA) y psicológico (cuestionarios). Esto permitió cuantificar de manera objetiva y a tiempo real el efecto de variables de diseño de distinta modalidad; algo que no es posible sólo a través de metodologías tradicionales. En relación a las modalidades, cabe destacar la importancia en el diseño de incorporar estimulación auditiva y olfativa, y la sinergia que se da entre distintas modalidades si están enfocadas a un mismo fin. El proceso muestra que las herramientas de simulación ambiental y de registro neurofisiológico, a las que recurre la neuroarquitectura, pueden ser incorporadas con éxito a protocolos experimentales que incluyan metodologías tradicionales. Tanto las aproximaciones más tradicionales como las más novedosas ofrecen directrices de diseño fundamentadas. Combinarlas permite una mayor profundidad en el análisis de la dimensión cognitivo-emocional de la arquitectura.

De acuerdo a lo explorado a través de la presente Tesis Doctoral, podrían destacarse dos líneas de futura investigación: 1) índices sobre la experiencia cognitivo-emocional de la arquitectura; y 2) modelos predictivos sobre las variables de diseño. La primera línea (índices sobre la experiencia) se refiere al desarrollo de algoritmos, basados en métricas neurofisiológicas y comportamentales, capaces de predecir aspectos sobre la experiencia cognitivo-emocional del usuario en el espacio arquitectónico. Estos facilitarían el trabajo de descifrar la experiencia arquitectónica a través de las métricas fisiológicas; un desafío actual por el cual la aplicación práctica de la neuroarquitectura podría verse ralentizada (en el SO5 se exploró la cuantificación neurofisiológica del estrés, aprovechando que sus bases neurofisiológicas se han estudiado más clínicamente). Los índices (no métricas) seguirían teniendo las mismas ventajas de los registros neurofisiológicos: objetividad, y registro a tiempo real; pero incluirían la ventaja de ser más fácilmente interpretables. Se podrían desarrollar distintos índices. Por ejemplo, sobre los ya comentados modelos emocionales de Külller (*affection, complexity, enclosedness, originality, pleasantness, potency, social status, unity)* o de Mehrabian & Russel (*pleasure, arousal, dominance*). Sobre este último, ya se han desarrollado iniciativas en el contexto de la arquitectura que indican que cierto grado de éxito es posible (Marín-Morales et al., 2018). Pero también podrían desarrollarse índices sobre constructos más complejos como el bienestar; el cual supondría un avance substancial para evaluar el diseño de espacios arquitectónicos. Cuando esto se alcance, y los dispositivos de registro neurofisiológicos sean menos invasivos, será posible incluso modificar automáticamente el espacio de acuerdo a cuestiones cognitivo-emocionales utilizando el internet de las cosas (la conexión de objetos cotidianos a internet). Por ejemplo: modificar la iluminación para apoyar un posible estado de estrés. La segunda línea (modelos sobre variables) se refiere al desarrollo de algoritmos capaces de predecir los efectos (psicológicos o neurofisiológicos) cognitivo-emocionales de los usuarios ante determinadas variables de diseño, para buscar la combinación idónea de ellas. La mayoría de las metodologías experimentales actuales se basan en fuerza bruta: estudian los efectos cognitivo-emocionales de las variables de diseño a través de distintas configuraciones de sus parámetros, una a una. Por ejemplo, para estudiar la variable iluminación, ésta se divide en parámetros como la iluminancia y la temperatura de color, y cada uno de estos parámetros recibe varias configuraciones. Suponiendo un estudio de cinco variables de tres parámetros con tres configuraciones cada uno, sería necesario evaluar 135 opciones de diseño. Algo dificultoso experimentalmente, a pesar de la reducción de variables (prácticamente cualquier espacio real está configurado por más de cinco variables; cualquier variable tiene más de 3 parámetros significativos; y, más aún, cualquier parámetro tiene más de tres configuraciones). Una situación experimental análoga hubiera ocurrido en el artículo centrado en abordar el SO5 si las variables de diseño no se hubieran agrupado en *interior design* y *ambient environment*. Contar con algoritmos predictivos (que sí podrían generarse a partir de la base de datos de este tipo de estudios) permitiría un estudio más exhaustivo del efecto cognitivo-emocional de las variables de diseño; que de otra manera sería irrealizable por tiempo y recursos. Aproximaciones similares ya han sido empleadas en el diseño de avatares (Diego-Mas & Alcaide-Marzal, 2015). Así, el avance de la neuroarquitectura (analizado con mayor detenimiento a través del SO1) no depende sólo, como se adelantó en la discusión, de la capacidad de las herramientas en que se basa (exploradas a través de los SO2, SO3, y SO5) para superar sus desafíos. Tiene sus propios retos.

En los últimos años, la aplicación de la neurociencia a la arquitectura se ha extendido. Este incremento de su popularidad, da lugar a algunas controversias: fundamentalmente, en torno a su nombre y su repercusión. En cuanto su nombre, el término “neuroarquitectura” tiene inconvenientes conceptuales, técnicos, y académicos. A nivel conceptual, probablemente no haga justicia a la arquitectura ni a la neurociencia. Pudiera parecer que relega la neurociencia a un papel meramente instrumental, y la arquitectura a meramente contextual. Roles que poco tienen que ver con una disciplina verdaderamente transdisciplinar. A nivel técnico, la imprecisión del término hace que no funcione bien en búsquedas informatizadas (por ejemplo, se mezcla con contenidos relacionados con la arquitectura neuronal o con la inteligencia artificial). Por su parte, a nivel académico no queda claro si incluye trabajos que no utilicen registros neurofisiológicos (por ejemplo, aquellos basados en tareas psicológicas). En este sentido, puede que la neuroarquitectura esté llamada a funcionar a modo de término paraguas. Aunque otros términos podrían haber funcionado mejor al respecto, ya es difícil adoptarlos debido a la cantidad de documentación generada. Indistintamente, no cabe duda de que funciona bien a nivel promocional, lo cual es positivo porque contribuye a acercar el conocimiento a la sociedad; su fin último. En cuanto a la repercusión, existen críticas sobre sus posibilidades. Desde algunos puntos de vista, la aceptación de directrices de diseño externas infringe cuestiones profundamente establecidas en las *designerly ways of knowing* que dirigen el proceso proyectual. Sin embargo, la neuroarquitectura no tiene por objeto el imposible de reducir el diseño a normas universales. Por lo tanto, no eliminará la labor de los profesionales de la arquitectura y el diseño, sino que complementará las herramientas (más o menos puestas en práctica) con las que ya cuentan para abordar la dimensión cognitivo-emocional de la arquitectura. Así, los conocimientos que ofrece la neuroarquitectura ayudarán a satisfacer más ampliamente las necesidades de los usuarios. Comprender los fundamentos en los que se basa la experiencia arquitectónica no la hace menos relevante. Llevará años de investigación y desarrollo para que la neuroarquitectura, aún incipiente, permita diseñar proyectos enteramente usando las bases neurofisiológicas de la experiencia arquitectónica. No obstante, el camino resulta emocionante.

09. Conclusions

The objective of this doctoral thesis, "Neuroarchitecture: new architectural design metrics through the application of neurotechnologies", is to contribute to the research and design of the cognitive-emotional dimension of architecture. This requires exploration of both theoretical and practical issues. The task is divided into five sub-objectives. Sub-objective SO1 examines the study of the cognitive-emotional dimension of architecture from a modern perspective that contextually integrates traditional and new approaches. Sub-objectives SO1 and SO3 examine the usefulness of the major environmental simulation systems. SO4 assesses the knowledge that the combination of quantitative and traditional qualitative methodologies offers to the study of the cognitive-emotional dimension of architecture. Finally, sub-objective SO5 examines the potential, for the same purpose, of the joint use of the environmental simulation tools validated in the first two sub-objectives, and some of the methodologies evaluated in the third sub-objective, and neurophysiological measurement systems. The sub-objectives seek to provide knowledge of human responses to specific situations. SO2 and SO3 discuss proposals related to environmental simulation systems, and SO1, SO4 and SO5 related to design guidelines. Moreover, together, the five sub-objectives provide a methodological contribution of particular importance in the absence of a commonly accepted experimental framework for neuroarchitecture. This varied contribution, together with the marked transdisciplinary nature of the doctoral thesis, made it appropriate to publish material about the sub-objectives in journals with differing principal knowledge domains.

SO1 (published in the journal "Sensors") was addressed through a neuroarchitecture-focussed scoping review. This type of review provides a broad perspective of complex issues based on heterogeneous sources. Through a bibliographic analysis of 612 references, located and consulted during the development of the doctoral thesis, this article draws a map of the different areas relevant to the issue. Among the main results of the article are: (1) the identification and synthesis of the main traditional approaches (geometry, phenomenology of space, geographical experience, philosophy, environmental psychology and evidence based design) and new approaches (neuroscience and virtual reality, including a review of related tools and methods); (2) an analysis of the effect of different design variables based on these approaches (which is useful at the experimental development level, to guide the analysis, and in the development of design guidelines); and (3) a discussion about the state of the art and future research lines for the study of the cognitive-emotional dimension of architecture. This is particularly important in the specific case of neuroarchitecture as it is usually presented in a decontextualised way; this can create prejudices about its current possibilities and future developments.

Sub-objectives SO2 and SO3 address the application of current environmental simulation systems from different perspectives. SO2 (published in the journal "Applied Ergonomics") focused on their application in environmental psychology; and SO3 (published in the journal "EGA Journal of Architectural Graphic Expression/EGA Revista de Expresión Gráfica Arquitectónica") on their application in design. With regard to their application in environmental psychology, it was found that the 360o panorama and virtual reality formats represented an advance on the usual photography-based approaches. Simulated environments that used both formats generated psychological and physiological responses more similar to those generated by the physical environments they represented (particularly the 360o presentation). Different formats and devices were addressed in their application to design. The 360o panorama and virtual reality formats were shown to be preferred, also as design tools; the evaluations of the panoramas were higher that the evaluations of virtual reality. In relation to the devices used, HMDs got better ratings than computer screens, despite screens being more familiar to most users. In general, these results indicate the greater capacities of the new formats and devices, both for studying the cognitive-emotional responses of users in simulated environments (similar to the issues addressed in SO5) and in support of the design process. These design advantages have not yet, despite the increasing availability of compatible professional software, led to general adoption. However, in the environmental psychology field a growing number of articles using these systems have been published.

The last two sub-goals of the five that make up the main body of the doctoral thesis address different approaches to the cognitive-emotional dimension of architecture. SO4 (published in HERD, "Health Environments Research & Design Journal") focused on combining the quantitative and qualitative methodologies used in traditional approaches. SO5 (published in the "Building Research & Information" journal) addressed the use of the new environmental simulation systems in conjunction with neurophysiological and psychological measurements. The combination of the traditional methodologies helped identify the set of emotional factors and the conceptual structure behind users' evaluations of spaces. On the one hand, the use of focus groups is appropriate for two reasons: to gather information about users' needs, and to collect data on concepts related to the affective-emotional experience of particular spaces. On the other hand, semantic differentials allow the extraction of the conceptual structure underlying these concepts (which, if obtained from other sources, may not be representative of the user). As to the use of new tools, the work undertaken in this doctoral thesis has shown that visual (through HMD-based 360o panoramas), hearing (through headphones) and olfactory (through fragrance dispensers) environmental simulation approaches are compatible with neurophysiological (EEG, HRV, EDA) and psychological (questionnaires) measures. These allow the real-time objective quantification of the effects of design variables of different modalities, impossible using only traditional methodologies. In relation to the design of modalities it is important to highlight the benefits of incorporating auditory and olfactory stimulation, and the synergies that develop between different modalities when they are focused on the same purpose. This process has demonstrated that the environmental simulation and neurophysiological recording tools used in neuroarchitecture can be successfully incorporated into experimental protocols that include traditional methodologies. Both the traditional and new approaches offer substantiated design guidelines. Combining them provides greater depth to the analysis of the cognitive-emotional dimension of architecture.

As explored in this doctoral thesis, two lines of future research can be highlighted: 1) indixes of the cognitive-emotional experience of architecture; and 2) predictive models for design variables. The first line (experience indexes) addresses the development of algorithms, based on neurophysiological and behavioural metrics, that can predict aspects of the user's cognitive-emotional experiences in architectural spaces. These would facilitate the task of deciphering the architectural experience through physiological metrics; this is a current challenge which might slow the practical application of neuroarchitecture (SO5 explores the neurophysiological quantification of stress, taking advantage of the clinical studies into its neurophysiological bases). Indexes (i.e., not metrics) would retain the advantages of neurophysiological records, objectivity and real-time recording, but they would have the advantage of being more easily interpretable. Different indexes could be developed, for example, based on the previously discussed emotional models of Külller (affection, complexity, enclosedness, originality, pleasantness, potency, social status, unity) and Mehrabian and Russel (pleasure, arousal, dominance). Initiatives based on Mehrabian and Russel's work have previously been developed in the context of architecture and have suggested that a certain degree of success in this area is possible (Marín-Morales et al., 2018). Indexes could also be developed on more complex constructs such as well-being; this would be a substantial step forward in the evaluation of the design of architectural spaces. When this has been achieved, and neurophysiological recording devices are less invasive, it will even be possible to automatically modify spaces based on cognitive-emotional aspects using the Internet of Things (connecting everyday objects to the internet). For example, by modifying lighting to reduce stress levels. The second line (predictive models) relates to the development of algorithms capable of predicting the cognitive-emotional (psychological and/or neurophysiological) effects on users of specific design variables; this would allow researchers to identify ideal combinations. Most current experimental methodologies are based on brute force: they study the cognitive-emotional effects of design variables through different configurations of their parameters, one by one. For example, to study lighting, the variable is divided into parameters such as luminance and colour temperature, and each of the parameters are given several configurations. In a study of five three-parameter variables, each with three configurations, it would be necessary to evaluate 135 design options. This would be experimentally difficult, despite the reduction of the number of variables (almost all real spaces are configured by more than five variables, all variables have more than 3 significant parameters and, moreover, all parameters have more than three configurations). An analogous experimental situation would have developed in the article that focused on SO5 if the design variables had not been grouped into interior design and ambient environment. Predictive algorithms (which could be generated from the databases of such studies) would support a more thorough examination of the cognitive-emotional effect of design variables than is currently possible due to time and resource constraints. Similar approaches have already been used in the design of avatars (Diego-Mas & Alcaide-Marzal, 2015). Thus, the advance of neuroarchitecture (analysed more closely in SO1) does not depend only, as proposed in the discussion, on the capacities of its associated measurement tools (explored in SO2, SO3 and SO5) to overcome the challenges it faces. The development of neuroarchitecture faces more challenges than just questions about the effectiveness of its associated disciplines and tools.

In recent years, the application of neuroscience in architecture has spread. This increase in its popularity has given rise to some controversies, mainly related to its name, neuroarchitecture, and to its impact. As for the name, the term "neuroarchitecture" has conceptual, technical and academic drawbacks. Conceptually, it probably doesn't do justice to either architecture or neuroscience. It arguably reduces neuroscience to a merely instrumental role, and architecture to a merely contextual role. These roles are not consonant with a truly transdisciplinary discipline. Technically, the imprecision of the term limits the value of computerised searches (e.g., it gets mixed up with content related to neural architecture and artificial intelligence). At the academic level it is not clear whether neuroarchitecture includes works that do not use neurophysiological recordings (e.g., those based on psychological tasks). In this sense, neuroarchitecture may be called on to operate as an umbrella term. While other terms may have worked better, it would be difficult now to adopt them due to the amount of documentation already generated. Equally, the term certainly works well at the promotional level, which is positive because this helps increase awareness of the topic among wider society, the ultimate objective. As to its impact, there are criticisms of its possibilities. From some viewpoints, acceptance of external design guidelines would violate issues deeply established in the designerly ways of knowing that guide the project process. However, neuroarchitecture is not intended to reduce design to universal standards. Therefore, it will not eliminate the work of architecture and design professionals, but will complement the tools (more or less already put into practice) that they currently use to address the cognitive-emotional dimension of architecture. Thus, the knowledge offered by neuroarchitecture will help to more broadly meet users' needs. Understanding the fundamentals on which architectural experience is based does not make it any less important. It will take years of research and development for the still incipient neuroarchitecture to design entire projects using only the neurophysiological foundations of the architectural experience. However, the road ahead is exciting.

09. Conclusioni

L'obiettivo della presente tesi di dottorato, "Neuroarchitettura: nuove metriche per la progettazione architettonica mediante l'uso di neurotecnologie", è contribuire alla ricerca e alla strutturazione della dimensione cognitivo-emozionale dell'architettura. Tale scopo ha richiesto un'analisi di aspetti tanto teorici quanto pratici. L'obiettivo è stato diviso in cinque sotto-obiettivi. Per il sotto-obiettivo SO1 si è esaminato lo studio della dimensione cognitivo-emozionale dell'architettura da una prospettiva attuale, che combina in maniera contestualizzata gli approcci tradizionali e quelli nuovi. Per i sotto-obiettivi SO2 e SO3 si è studiata l'utilità dei principali sistemi di simulazione ambientale. Il sotto-obiettivo SO4 è stato incentrato sulla verifica delle conoscenze che una combinazione delle metodologie quantitative e qualitative tradizionalmente utilizzate può offrire allo studio della dimensione cognitivo-emozionale dell'architettura. Infine, nel sotto-obiettivo SO5 sono state analizzate le potenzialità dell'utilizzo congiunto degli strumenti di simulazione ambientale verificati nei primi due sotto-obiettivi in combinazione con una parte delle metodologie esaminate nel terzo e con sistemi di misurazione neurofisiologica. Ognuno dei sotto-obiettivi offre informazioni sulla risposta umana dinanzi a situazioni concrete; nello specifico, i sotto-obiettivi SO2 e SO3 forniscono nozioni per la scelta di un sistema di simulazione ambientale e i sotto-obiettivi SO1, SO4 e SO5 forniscono indicazioni in merito alla progettazione. Inoltre, nell'insieme, i cinque sotto-obiettivi costituiscono un contributo metodologico particolarmente di rilievo se consideriamo che in neuroarchitettura non esiste un quadro sperimentale comune accettato. Questa varietà di contributi, in combinazione con il carattere marcatamente transdisciplinare della presente Tesi di Dottorato, è la ragione per cui i sotto-obiettivi sono stati pubblicati all'interno di riviste di differenti aree del sapere.

Il sotto-obiettivo SO1 (pubblicato nella rivista "Sensors") è stato trattato mediante una *scoping review* (revisione dell'ambito) della neuroarchitettura. Questo tipo di revisioni consente di presentare una prospettiva ampia su questioni complesse in cui intervengono fonti eterogenee. Attraverso un'analisi bibliografica di 612 riferimenti, localizzati e consultati nel corso dello sviluppo della Tesi di Dottorato, l'articolo traccia una mappa delle varie aree che interessano la questione. Tra i principali risultati dell'articolo si trovano: (1) un'identificazione e una sintesi dei principali approcci tradizionali (geometria, fenomenologia dello spazio, geografia dell'esperienza, filosofia, psicologia ambientale e *evidence based design*) e degli approcci nuovi (neuroscienza e realtà virtuale, dei quali si menzionano anche gli strumenti e i metodi); (2) l'effetto delle diverse variabili di progettazione in base agli approcci precedenti (utile a livello di sviluppo sperimentale per orientare l'analisi, nonché come indicazioni per la progettazione); e (3) un dibattito sullo stato attuale e sulle evoluzioni future dello studio della dimensione cognitivo-emozionale dell'architettura. Nel caso concreto della neuroarchitettura, questo punto è particolarmente importante considerando che viene solitamente presentata in maniera decontestualizzata, il che genera pregiudizi sulle sue possibilità attuali e sui suoi sviluppi futuri.

Nei due sotto-obiettivi successivi si è esaminata l'applicazione di sistemi di simulazione ambientale attuali da varie prospettive. Il sotto-obiettivo SO2 (pubblicato nella rivista "Applied Ergonomics") è stato incentrato sull'applicazione nella psicologia ambientale e il sotto-obiettivo SO3 (pubblicato nella rivista "EGA Revista de Expresión Gráfica Arquitectónica") sull'applicazione nell'ambito della progettazione. Per quel che riguarda l'applicazione nell'ambito della psicologia ambientale, è stato rilevato che i formati della realtà virtuale e della panoramica a 360º rappresentano un passo avanti rispetto alla fotografia tradizionale. Gli ambienti simulati mediante questi due formati generano una risposta psicologica e fisiologica più simile a quella che generano gli ambienti fisici rappresentati, soprattutto la panoramica a 360º. Sul fronte dell'applicazione nell'ambito della progettazione sono stati utilizzati vari formati e vari supporti. Per quel che riguarda i formati, la panoramica a 360º e la realtà virtuale sono i preferiti anche come strumenti di progettazione; tra i due formati, il primo è quello con le migliori valutazioni. Per quel che riguarda i supporti, l'HMD ha ottenuto valutazioni migliori rispetto allo schermo del computer (nonostante quest'ultimo sia più familiare alla maggior parte degli utenti). In generale, questi risultati evidenziano maggiori capacità nei nuovi formati e nei nuovi supporti, sia per studiare la risposta cognitivo-emozionale degli utenti attraverso ambienti simulati (simili a quelli esaminati nel sotto-obiettivo SO5) sia per favorire il processo della progettazione. Nonostante la compatibilità di un numero sempre maggiore di software professionali, questo vantaggio per la progettazione non ha ancora trovato un'adozione generale. Nell'ambito della psicologia ambientale, tuttavia, troviamo un numero crescente di articoli pubblicati che utilizzano questi sistemi.

Gli ultimi due sotto-obiettivi, dei cinque che compongono il corpo principale della Tesi di Dottorato, hanno affrontato l'utilizzo di vari approcci alla dimensione cognitivo-emozionale dell'architettura. Il sotto-obiettivo SO4 (pubblicato nella rivista "HERD: Health Environments Research & Design Journal") è stato incentrato sulla combinazione delle metodologie quantitative e qualitative degli approcci tradizionali e il sotto-obiettivo SO5 (pubblicato nella rivista "Building Research & Information") sull'uso di nuovi sistemi di simulazione ambientale in combinazione con la misurazione neurofisiologica e psicologica. La combinazione di metodologie tradizionali ha consentito di identificare l'insieme dei fattori emozionali e la struttura concettuale alla base delle valutazioni degli utenti sullo spazio. Da un lato, l'uso di *focus group* risulta adeguato per due finalità, ovvero ispezionare le informazioni sulle necessità degli utenti e raccogliere i concetti relativi all'esperienza affettivo-emozionale di uno spazio concreto. Dall'altro, la semantica differenziale consente di estrarre la struttura concettuale soggiacente ai concetti precedenti (che, se provengono da un'altra fonte, possono non essere rappresentativi dell'utente). In merito all'utilizzo di nuovi strumenti, la simulazione ambientale visiva (mediante panoramiche a 360º mostrate su uno schermo HMD), uditiva (mediante cuffie) e olfattiva (mediante dispenser di fragranze) risulta compatibile con la registrazione neurofisiologica (EEG, HRV e EDA) e psicologica (questionari). Ciò ha consentito di quantificare in maniera oggettiva e in tempo reale l'effetto di variabili di progettazione di diversa modalità, una quantificazione non ottenibile con il solo utilizzo di metodologie tradizionali. In relazione alle modalità, occorre sottolineare l'importanza dell'integrazione della stimolazione uditiva e olfattiva per la progettazione e la sinergia che si crea tra modalità diverse se incentrate su uno stesso obiettivo. Il processo mostra che gli strumenti di simulazione ambientale e di registrazione neurofisiologica ai quali ricorre la neuroarchitettura possono essere efficacemente integrati all'interno di protocolli sperimentali che includano metodologie tradizionali. Tanto gli approcci più tradizionali quanto quelli più innovativi offrono indicazioni di progettazione fondamentali. La loro combinazione consente un'analisi più approfondita della dimensione cognitivo-emozionale dell'architettura.

In base a quanto analizzato mediante la presente Tesi di Dottorato, si potrebbero evidenziare due linee di ricerca per il futuro: 1) indici sull'esperienza cognitivo-emozionale dell'architettura; e 2) modelli predittivi sulle variabili di progettazione. La prima linea (indici sull'esperienza) si riferisce allo sviluppo di algoritmi basati su metriche neurofisiologiche e comportamentali in grado di prevedere aspetti correlati all'esperienza cognitivo-emozionale dell'utente nello spazio architettonico. Tali algoritmi agevolerebbero la decifrazione dell'esperienza architettonica tramite le metriche fisiologiche; si tratta di una sfida molto attuale che potrebbe rallentare l'applicazione pratica della neuroarchitettura (nel sotto-obiettivo SO5 è stata analizzata la quantificazione neurofisiologica dello stress, sfruttando il fatto che i suoi aspetti neurofisiologici sono stati studiati in maniera più clinica). Gli indici (non le metriche) continuerebbero ad avere gli stessi vantaggi delle registrazioni neurofisiologiche (oggettività e registrazione in tempo reale), con il vantaggio aggiunto di una maggiore facilità di interpretazione. Si potrebbero sviluppare vari indici. Ad esempio, sui già menzionati modelli emozionali di Küller (*affection, complexity, enclosedness, originality, pleasantness, potency, social status, unity)* o di Mehrabian & Russel (*pleasure, arousal, dominance*). Su quest'ultimo, sono già state svolte alcune iniziative nel contesto dell'architettura che hanno dimostrato che esistono possibilità di esito positivo (Marín-Morales et al., 2018). Tuttavia, si potrebbero anche sviluppare indici su costrutti più complessi come il benessere, il che rappresenterebbe un progresso sostanziale per la valutazione della progettazione di spazi architettonici. Nel momento in cui si raggiungerà questo obiettivo e i dispositivi di registrazione neurofisiologica saranno meno invasivi, sarà persino possibile modificare automaticamente lo spazio in base ad aspetti cognitivo-emozionali utilizzando l'*Internet of Things* (ovvero la connessione di oggetti quotidiani a Internet). Ad esempio, si potrebbe modificare l'illuminazione in base a un possibile stato di stress. La seconda linea (modelli su variabili) si riferisce allo sviluppo di algoritmi in grado di prevedere gli effetti (psicologici o neurofisiologici) cognitivo-emozionali degli utenti dinanzi a determinate variabili di progettazione per cercare la combinazione più adeguata di tali variabili. La maggioranza delle metodologie sperimentali attuali si basa sulla forza bruta: studia gli effetti cognitivo-emozionali delle variabili di progettazione attraverso le varie configurazioni dei loro parametri, una ad una. Ad esempio, per studiare la variabile illuminazione, la si suddivide in parametri, come l'illuminamento e la temperatura del colore, e ognuno di questi parametri riceve varie configurazioni. Supponendo uno studio di cinque variabili di tre parametri con tre configurazioni ognuno, sarebbe necessario valutare 135 opzioni di progettazione. Una valutazione difficile a livello sperimentale, nonostante la riduzione delle variabili (praticamente qualunque spazio reale è configurato da più di cinque variabili, praticamente qualunque variabile possiede più di tre parametri significativi e, ancor di più, praticamente qualunque parametro presenta più di tre configurazioni). Una situazione sperimentale analoga si sarebbe verificata nell'articolo incentrato sul sotto-obiettivo SO5 se le variabili di progettazione non fossero state raggruppate in *interior design* e *ambient environment*. Poter contare su algoritmi predittivi (che si potrebbero generare a partire dal database di questo tipo di studi) permetterebbe uno studio più esaustivo dell'effetto cognitivo-emozionale delle variabili di progettazione, uno studio altrimenti irrealizzabile per questioni di tempo e risorse. Approcci simili sono già stati utilizzati nella progettazione di avatar (Diego-Mas & Alcaide-Marzal, 2015). Allo stesso modo, come già anticipato nella discussione, il progresso della neuroarchitettura (analizzato in maniera più approfondita tramite il sotto-obiettivo SO1) non dipende solo dalle potenzialità degli strumenti su cui si basa (analizzati tramite i sotto-obiettivi SO2, SO3 e SO5) per poter superare le sue sfide. Presenta infatti delle sfide intrinseche.

Negli ultimi anni, l'applicazione della neuroscienza all'architettura si è espansa. Questo aumento di popolarità ha dato luogo ad alcune controversie, sostanzialmente correlate al suo nome e alla sua ripercussione. Per quanto riguarda il suo nome, il termine "neuroarchitettura" implica degli inconvenienti concettuali, tecnici e accademici. A livello concettuale, probabilmente non rende giustizia né all'architettura né alla neuroscienza. Potrebbe sembrare che relega la neuroscienza a un ruolo meramente strumentale e l'architettura a un ruolo meramente contestuale. Ruoli poco rappresentativi di una disciplina realmente transdisciplinare. A livello tecnico, l'imprecisione del termine lo rende poco funzionale alle ricerche informatiche (ad esempio, si confonde con contenuti correlati all'architettura neuronale o all'intelligenza artificiale). A livello accademico, poi, non risulta chiaro se include lavori che non utilizzino registrazioni neurofisiologiche (ad esempio, quelle basate su attività psicologiche). In questo senso, neuroarchitettura potrebbe fungere da termine generico. Sebbene possano esistere altri termini più idonei, allo stato attuale sarebbe difficile adottarli a causa della quantità di documentazione correlata già generata. Senza alcun dubbio, questo termine funziona bene a livello promozionale, il che è positivo perché contribuisce ad avvicinare il sapere alla società, il suo fine ultimo. In quanto alla sua ripercussione, sono state mosse critiche alle sue possibilità. Da alcuni punti di vista, l'accettazione di indicazioni di progettazione esterne viola alcuni aspetti profondamente radicati nei *designerly ways of knowing* che dirigono il processo progettuale. Tuttavia, la neuroarchitettura non si prefigge l'obiettivo impossibile di ridurre la progettazione a norme universali. Pertanto, non eliminerà la figura dei professionisti dell'architettura e della progettazione, ma aggiungerà degli strumenti integrativi (più o meno messi in pratica) a quelli già utilizzati con il fine di affrontare la dimensione cognitivo-emozionale dell'architettura. In questo modo, le conoscenze offerte dalla neuroarchitettura contribuiranno ad un più ampio soddisfacimento delle esigenze degli utenti. Comprendere le nozioni su cui si basa l'esperienza architettonica non la rende meno rilevante. Ci vorranno anni di ricerca e sviluppo perché la neuroarchitettura, ancora incipiente, possa consentire una progettazione integralmente basata sui principi neurofisiologici dell'esperienza architettonica. Eppure, non potrebbe esserci cammino più emozionante.

Actividades de Investigación

Research activities

El desarrollo de la presente Tesis Doctoral involucró distintas actividades de investigación. Este apartado recoge las más representativas y afines a su objetivo general y sus sub-objetivos. Entre ellas, los cinco artículos independientes recogidos en los capítulos 3 a 7. No incluye otras actividades propias de aplicar las metodologías y herramientas estudiadas a proyectos de ámbitos diferentes. Por tanto, no constituye un resumen del *currículum vitae* relativo al período de ejecución; sino una muestra de la labor de investigación desarrollada en el marco de la Tesis Doctoral.

The development of this Doctoral Thesis involved different research activities. This section includes the most representative and related to its general objective and sub-objectives. Among them, the five independent journal papers collected in chapters 3 to 7. It does not include other activities related to applying the methodologies and tools studied to projects in different fields. Therefore, it does not constitute a summary of the curriculum vitae relating to the period of execution; but rather a sample of the research work carried out within the framework of the Doctoral Thesis.

1. Proyectos de investigación / Research projects

1.1. Investigación de nuevas métricas de neuroarquitectura mediante el uso de entornos virtuales inmersivos (TIN2013-45736-R)

- **Entidad financiadora:** Ministerio de Economía Industria y Competitividad
- **Duración:** 16/07/2015 a 30/06/2016
- **Investigador principal:** Llinares Millán, María del Carmen
- **Importe de la subvención:** 134.552,00 €

1.2. Desarrollo de un índice cognitivo-emocional para cuantificar la percepción de seguridad del peatón. Aplicación a espacios urbanos (SPIP2017-02220)

- **Entidad financiadora:** Dirección General de Tráfico, Ministerio del Interior
- **Duración:** 05/04/2018 a 01/11/2018
- **Investigador principal:** Llinares Millán, María del Carmen
- **Importe de la subvención:** 37.620,00 €

1.3. El diseño del aula para potenciar los procesos cognitivos del alumnado: una propuesta metodológica para evaluar las variables luz, color y forma (BIA2017-86157-R)

- **Entidad financiadora:** Ministerio de Ciencia, Innovación y Universidades
- **Duración:** 21/12/2018 a 01/11/2021
- **Investigador principal:** Llinares Millán, María del Carmen
- **Importe de la subvención:** 108.900,00 €

1.4. Sound and illumination: multisensory design guidelines for university classrooms

- **Entidad financiadora:** The Academy of Neuroscience for Architecture (ANFA)
- **Duración:** 01/09/2020 a 01/09/2021
- **Investigador principal:** Higuera Trujillo, Juan Luis
- **Importe de la subvención:** 9.454,50 $

2. Estancia de investigación / Research internship

2.1. Monterrey (México)

- **Centro:** Instituto Tecnológico y de Estudios Superiores de Monterrey
- **Localidad:** Monterrey
- **País:** México
- **Duración:** 07/02/2020 a 08/05/2020

3. Artículos de revista / Journal papers

3.1. Entornos virtuales online y diseño centrado en el usuario: un estudio de caso

- **Autores:** López-Tarruella Maldonado, Juan; Llinares Millán, María del Carmen; Guixeres Provinciale, Jaime; Higuera-Trujillo, Juan Luis
- **Año:** 2016
- **Revista:** DYNA
- **Editorial:** Federación de Asociaciones de Ingenieros Industriales de España
- **ISSN:** 0012-7361
- **Índice de impacto (JCR 2016):** 0.541
- **Categoría y posición:** Engineering, Multidisciplinary - 70/85
- **Volumen:** 91
- **Páginas:** 634 - 638

3.2. Emotional maps: neuro-architecture and design applications

- **Autores:** Higuera-Trujillo, Juan Luis; Marín-Morales, Javier; Rojas-López, Juan Carlos; López-Tarruella Maldonado, Juan
- **Año:** 2016
- **Revista:** RDIS: Revista de la Red Internacional de Investigación en Diseño
- **Editorial:** Escuela Técnica Superior de Ingeniería del Diseño
- **ISSN:** 2254-7215
- **Volumen:** 2
- **Páginas:** 276 - 284

3.3. El espacio digital: comparativa de las últimas técnicas de visualización arquitectónica

- **Autores:** Higuera-Trujillo, Juan Luis; López-Tarruella, Juan; Llinares-Millán, María del Carmen; Iñarra-Abad, Susana
- **Año:** 2017
- **Revista:** EGA: Revista de Expresión Gráfica Arquitectónica
- **Editorial:** Asociación Española de Departamentos Universitarios de Expresión Gráfica Arquitectónica
- **ISSN:** 1133-613
- **Índice de impacto (SJR 2017):** 0.107
- **Categoría y posición:** Architecture - 108/151; Visual arts and performing arts – 237/456
- **Volumen:** 22
- **Páginas:** 105 - 111

3.4. Psychological and physiological human's responses to simulated and real environments: A comparison between Photograph, 360º Panorama and Virtual Reality

- **Autores:** Higuera-Trujillo, Juan Luis; López-Tarruella, Juan; Llinares-Millán, María del Carmen
- **Año:** 2017
- **Revista:** Applied Ergonomics
- **Editorial:** Elsevier
- **ISSN:** 0003-6870
- **Índice de impacto (JCR 2017):** 2.435
- **Categoría y posición:** Ergonomics - 2/16; Psychology applied - 25/82; Engineering, industrial - 16/47
- **Volumen:** 65
- **Páginas:** 398 - 409

3.5. Affective computing in virtual reality: emotion recognition from brain and heartbeat dynamics using wearable sensors

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; Greco, Alberto; Guixeres Provinciale, Jaime; Llinares Millán, María del Carmen; Scilingo, Enzo Pasquale; Alcañiz Raya, Mariano Luis; Valenza, Gaetano
- **Año:** 2018
- **Revista:** Scientific Reports
- **Editorial:** Springer Nature
- **ISSN:** 2045-2322
- **Índice de impacto (JCR 2018):** 4.011
- **Categoría y posición:** Multidisciplinary sciences - 15/69
- **Volumen:** 8
- **Páginas:** 13657

3.6. Navigation Comparison between a Real and a Virtual Museum: Time-dependent Differences using a Head Mounted Display

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; de Juan-Ripoll, Carla;
Llinares Millán, María del Carmen; Guixeres Provinciale, Jaime; Alcañiz Raya, Mariano Luis
- **Año:** 2019
- **Revista:** Interacting with Computers
- **Editorial:** Oxford Academic
- **ISSN:** 0953-5438
- **Índice de impacto (JCR 2019):** 1.036
- **Categoría y posición:** Computer science, cybernetics - SCIE - 19/22; Ergonomics - SSCI - 15/16
- **Volumen:** 31
- **Páginas:** 208 - 222

3.7. Real vs. immersive-virtual emotional experience: Analysis of psycho-physiological patterns in a free exploration of an art museum

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; Greco, Alberto; Guixeres Provinciale, Jaime; Llinares Millán, María del Carmen; Gentili, Claudio; Scilingo, Enzo Pasquale; Alcañiz Raya, Mariano Luis; Valenza, Gaetano
- **Año:** 2019
- **Revista:** PLoS ONE
- **Editorial:** Public Library Science
- **ISSN:** 1932-6203
- **Índice de impacto (JCR 2019):** 2.740
- **Categoría y posición:** Multidisciplinary sciences - 27/71
- **Volumen:** 14
- **Páginas:** 1 - 24

3.8. Multisensory stress reduction: a neuro-architecture study of paediatric waiting rooms

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Montañana i Aviñó, Antoni; Rojas, Juan-Carlos
- **Año:** 2020
- **Revista:** Building Research & Information
- **Editorial:** Taylor & Francis
- **ISSN:** 2045-2322
- **Índice de impacto (JCR 2019):** 3.887
- **Categoría y posición:** Construction & building technology - SCIE - 12/63
- **Volumen:** 48
- **Páginas:** 269 - 285

3.9. Improving the Pedestrian's Perceptions of Safety on Street Crossings. Psychological and Neurophysiological Effects of Traffic Lanes, Artificial Lighting, and Vegetation

- **Autores:** Llinares, Carmen; Higuera-Trujillo, Juan Luis; Montañana, Antoni; Castilla, Nuria
- **Año:** 2020
- **Revista:** International Journal of Environmental Research and Public Health
- **Editorial:** MDPI
- **ISSN:** 1661-7827
- **Índice de impacto (JCR 2019):** 2.849
- **Categoría y posición:** Public, environmental & occupatioonal health - 32/171; Environmental sciences - 105/265
- **Volumen:** 17
- **Páginas:** 1 – 20

3.10. Cold and warm coloured classrooms. Effects on students' attention and memory measured through psychological and neurophysiological responses

- **Autores:** Llinares, Carmen; Higuera-Trujillo, Juan Luis; Serra Lluch, Juan
- **Año:** 2021
- **Revista:** Building and Environment
- **Editorial:** Elsevier

- **ISSN:** 0360-1323
- **Índice de impacto (JCR 2019):** 4.971
- **Categoría y posición:** Construction & Building Technology - 6/63; Engineering, Environmental - 12/53; Engineering, Civil – 4/134
- **Volumen:** 196
- **Páginas:** 107726

3.11. The Cognitive-Emotional Design and Study of Architectural Space: A Scoping Review of Neuroarchitecture and Its Precursor Approaches

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares, Carmen; Macagno, Eduardo
- **Año:** 2021
- **Revista:** Sensors
- **Editorial:** MDPI
- **ISSN:** 1424-8220
- **Índice de impacto (JCR 2019):** 3.275
- **Categoría y posición:** Instruments & Instrumentation - 15/64; Engineering, Electrical & Electronic - 77/266; Chemestry, Analytical - 22/86
- **Volumen:** 21
- **Páginas:** 2193

4. Capítulos de libro / Book chapters

4.1. Contribución de la Neuroarquitectura al diseño hospitalario

- **Autores:** Llinares Millán, Carmen; Guixeres Provinciale, Jaime; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan
- **Año:** 2014
- **Libro:** Catálogo de la Exposición de Tecnología e Investigación científica en Edificación
- **ISBN:** 978-84-697-1213-9
- **Editorial:** ETS Ingeniería Edificación Valencia
- **Páginas:** 144 - 149

4.2. Ingeniería Kansei, Realidad Virtual y medición Psicofisiológica para el diseño de espacios emocionalmente eficientes

- **Autores:** Llinares Millán, Carmen; Guixeres Provinciale, Jaime; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan
- **Año:** 2014
- **Libro:** Catálogo de la Exposición de Tecnología e Investigación científica en Edificación
- **ISBN:** 978-84-697-1213-9
- **Editorial:** ETS Ingeniería Edificación Valencia
- **Páginas:** 136 - 142

4.3. Identificación de directrices de diseño para espacios de neonatología

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María del Carmen; Montañana i Aviñó, Antoni; López-Tarruella Maldonado, Juan; Iñarra Abad, Susana; Guixeres Provinciale, Jaime
- **Año:** 2015
- **Libro:** Tecnología e Investigación en Edificación. EXCO 2015
- **ISBN:** 978-84-608-2650-7
- **Editorial:** Universitat Politècnica de València
- **Páginas:** 83 - 85

4.4. Diseño de espacios sanitarios mediante la aplicación de realidad virtual y medición psicofisiológica

- **Autores:** López-Tarruella Maldonado, Juan; Llinares Millán, María del Carmen; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; Guixeres Provinciale, Jaime
- **Año:** 2015
- **Libro:** Tecnología e Investigación en Edificación. EXCO 2015
- **ISBN:** 978-84-608-2650-7
- **Editorial:** Universitat Politècnica de València
- **Páginas:** 107 - 111

4.5. Identificación de directrices de diseño basadas en la experiencia del usuario

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María del Carmen; Montañana i Aviñó, Antoni
- **Año:** 2016
- **Libro:** El espacio interior y el usuario
- **ISBN:** 978-607-520-206-8
- **Editorial:** Universidad Autónoma de Ciudad Juárez
- **Páginas:** 93 - 106

4.6. Hacia un diseño emocional en la arquitectura: beneficios en los espacios sanitarios

- **Autores:** Guixeres Provinciale, Jaime; Higuera-Trujillo, Juan Luis; Montañana i Aviñó, Antoni
- **Año:** 2016
- **Libro:** El espacio interior y el usuario
- **ISBN:** 978-607-520-206-8
- **Editorial:** Universidad Autónoma de Ciudad Juárez
- **Páginas:** 144 - 155

4.7. EEG-index of stress generated by the environment: towards the neuroscience-based architectural design

- **Autores:** Higuera-Trujillo, Juan Luis; Marín-Morales, Javier; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen
- **Año:** 2017
- **Libro:** Investigando en Ingeniería de Edificación. EXCO 2017
- **ISBN:** 978-84-947525-1-3
- **Editorial:** Projectem Comunicació
- **Páginas:** 183 - 191

4.8. Neuroarchitecture: prediction of emotional well-being provoked by spaces by indirect measurement of brain activity

- **Autores:** López-Tarruella Maldonado, Juan; Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Martín-Morales, Javier
- **Año:** 2017
- **Libro:** Investigando en Ingeniería de Edificación. EXCO 2017
- **ISBN:** 978-84-947525-1-3
- **Editorial:** Projectem Comunicació
- **Páginas:** 193 - 201

4.9. Methodological proposal to analyse pedestrian's safety perception in urban areas

- **Autores:** Llinares Millán, Carmen; Montañana i Aviñó, Antoni; Llorens Rodríguez, Roberto; Martín-Morales, Javier; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana

- **Año:** 2018
- **Libro:** Investigando en Ingeniería de Edificación. EXCO'18
- **ISBN:** 978-84-17098-63-6
- **Editorial:** edita.me
- **Páginas:** 155 - 163

4.10. Dominance emotion recognition using physiological responses in immersive urban virtual environments

- **Autores:** Martín-Morales, Javier; Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen
- **Año:** 2019
- **Libro:** Investigando en Ingeniería de Edificación. EXCO'19
- **ISBN:** 978-84-17098-83-4
- **Editorial:** edita.me
- **Páginas:** 182 - 191

5. Congresos / Conferences

5.1. User's differences in spatial understanding by architectural plans and first-person interactive visualizations

- **Autores:** López-Tarruella Maldonado, Juan; Higuera-Trujillo, Juan Luis; Guixeres Provinciale, Jaime; Llinares Millán, María Del Carmen; Iñarra Abad, Susana
- **Año:** 2015
- **Congreso:** 3rd International Congress on Construction and Building Research - COINVEDI 2015
- **Lugar:** Madrid, España
- Ámbito: Internacional
- **Tipo:** Póster
- **ISSN:** 978-84-933567-6-7
- **Editorial:** Escuela Técnica Superior de Edificación
- **Páginas:** 39 - 40

5.2. Emotional cartography in design: A novel technique to represent emotional states altered by spaces

- **Autores:** Higuera-Trujillo, Juan Luis; Marín Morales, Javier; Rojas, Juan-Carlos; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen; Guixeres Provinciale, Jaime; Alcañiz Raya, Mariano
- **Año:** 2016
- **Congreso:** 3rd International Congress on Construction and Building Research - COINVEDI 2015
- **Lugar:** Amsterdam, Países Bajos
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-933567-6-7
- **Editorial:** The Design & Emotion Society
- **Páginas:** 562 - 566

5.3. Realidad Virtual como herramienta para la valoración emocional de entornos arquitectónicos

- **Autores:** López-Tarruella Maldonado, Juan; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; Llinares Millán, María Del Carmen; Guixeres Provinciale, Jaime; Alcañiz Raya, Mariano Luis
- **Año:** 2016
- **Congreso:** XVI Congreso Internacional de Expresión Gráfica Arquitectónica - EGA 2016
- **Lugar:** Alcalá de Henares, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-88754-39-4
- **Editorial:** Fundación General de la Universidad de Alcalá
- **Páginas:** 651 - 658

5.4. Identifying the perception variables to be taken into consideration when evaluating the integration of architectures with visual impact in the city

- **Autores:** Serra Lluch, Juan; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; Llinares Millán, Carmen
- **Año:** 2016
- **Congreso:** PPH International Conference on Social Science and Environment - PPH-SSE 2016
- **Lugar:** Vancouver, Canadá
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-88754-39-4
- **Editorial:** SMSSI Press
- **Páginas:** 34 - 40

5.5. The emerging render alternatives: a case study comparing the utility and aesthetics of the printed and the 360 in head-mounted display formats for architects and non-architects

- **Autores:** Higuera-Trujillo, Juan Luis; Rojas, Juan-Carlos; Pistoni Pérez, Mario; Iñarra Abad, Susana
- **Año:** 2017
- **Congreso:** ASME International Mechanical Engineering Congress and Exposition (IMECE 2017)
- **Lugar:** Tampa, USA
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-0-7918-5846-2
- **Editorial:** ASME
- **Páginas:** 1 - 6

5.6. Estrés percibido por los pacientes de centros de salud. Un estudio mediante integración de GSR y HRV como medidas alternativas a la respuesta mediante cuestionario

- **Autores:** Torrecilla Moreno, Carmen; Higuera-Trujillo, Juan Luis; de Juan-Ripoll, Carla; Guixeres Provinciale, Jaime; Alcañiz Raya, Mariano
- **Año:** 2017
- **Congreso:** IV Simposio Internacional de Innovación Aplicada (IMAT 2017)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-17129-21-7
- **Editorial:** ESIC Editorial
- **Páginas:** 58 - 59

5.7. Urban design tools: 360 panorama for studying pedestrians' perception of safety

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María Del Carmen; Castilla Cabanes, Nuria
- **Año:** 2018
- **Congreso:** 22nd International Congress on Project Management and Engineering (AEIPRO 2018)
- **Lugar:** Madrid, España
- **Ámbito:** Internacional
- **Tipo:** Artículo

- **ISSN:** 978-84-09-05132-8
- Editorial: AEIPRO
- **Páginas:** 591 - 600

5.8. Kansei Engineering application to classroom design

- **Autores:** Castilla Cabanes, Nuria; Llinares Millán, María Del Carmen; Blanca Giménez, Vicente; Higuera-Trujillo, Juan Luis
- **Año:** 2018
- **Congreso:** 22nd International Congress on Project Management and Engineering (AEIPRO 2018)
- **Lugar:** Madrid, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-09-05132-8
- **Editorial:** AEIPRO
- **Páginas:** 2375 - 2383

5.9. Printed and 360 Head-Mounted Display Rendering: A Cross-Cultural Study Comparing Utility, Spatial Representation and Emotional Capabilities

- **Autores:** Rojas, Juan-Carlos; Higuera-Trujillo, Juan Luis; Mora-Salinas, Roberto; Galindo, Jessica; Iñarra Abad, Susana
- **Año:** 2018
- **Congreso:** ASME International Mechanical Engineering Congress and Exposition (IMECE 2018)
- **Lugar:** Pittsburgh, USA
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-0-7918-5218-7
- **Editorial:** ASME
- **Páginas:** 1 - 6

5.10. The effect of urban design on the pedestrians' safety perception: lighting, vegetation, and roadway lanes

- **Autores:** Higuera-Trujillo, Juan Luis; Marín-Morales, Javier; Castilla Cabanes, Nuria; Iñarra Abad, Susana; Lloréns Rodríguez, Roberto; Montañana i Aviñó, Antoni.; Llinares Millán, Maria del Carmen
- **Año:** 2018
- **Congreso:** ICTCT 2018 Conference. On the track of future urban mobility: safety, human factors and technology
- **Lugar:** Porto, Portugal
- **Ámbito:** Internacional
- **Tipo:** Póster

5.11. Presence and navigation: a comparison between the free exploration of a real and a virtual museum

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; de Juan-Ripoll, Carla; Llinares Millán, María del Carmen; Guixeres Provinciale, Jaime; Iñarra Abad, Susana; Alcañiz Raya, Mariano Luis
- **Año:** 2018
- **Congreso:** 32nd Human Computer Interaction Conference (HCI 2018)
- **Lugar:** Belfast, UK
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **Páginas:** 1 - 6

5.12. Real vs. Immersive Virtual Emotional Museum Experience: a Heart Rate Variability Analysis during a Free Exploration Task

- **Autores:** Higuera-Trujillo, J.L.; Marín-Morales, J.; Castilla Cabanes, Nuria; Iñarra Abad, Susana; Lloréns, Roberto; Montañana i Aviñó, Antoni; Llinares Millán, María del Carmen.
- **Año:** 2020
- **Congreso:** 11th Conference of the European Study Group on Cardiovascular Oscillations (ESGCO 2020)
- **Lugar:** Pisa, Italia
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-1-7281-5751-1
- **Editorial:** IEEE
- **Páginas:** 1 – 2

5.13. Educational centres design tools. Virtual reality for the study of attention and memory performance

- **Autores:** Higuera-Trujillo, Juan Luis; Castellanos Baena, María Concepción; Llinares Millán, María Del Carmen
- **Año:** 2020
- **Congreso:** 14th International Technology, Education and Development Conference (INTED 2020)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-09-17939-8
- **Editorial:** IATED
- **Páginas:** 4362 - 4366

5.14. The influence of classroom design on memory and attention. A virtual reality study on lighting in University classrooms

- **Autores:** Higuera-Trujillo, Juan Luis; Castilla Cabanes, Nuria; Llinares Millán, María Del Carmen
- **Año:** 2020
- **Congreso:** 14th International Technology, Education and Development Conference (INTED 2020)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-09-17939-8
- **Editorial:** IATED
- **Páginas:** 4367 - 4372

5.15. An eye-tracking project in industrial design education: A case study for engaging in the research process

- **Autores:** Rojas, Juan-Carlos; Márquez Cañizares, Juan Carlos; Higuera-Trujillo, Juan Luis; Muniz, Gerardo
- **Año:** 2020
- **Congreso:** IEEE Education Engineering (EDUCON 2020)
- **Lugar:** Porto, Portugal
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-1-7281-0930-5
- Editorial: IEEE
- **Páginas:** 127 – 132

5.16. The cognitive effect of university classroom geometry. A virtual reality study focused on memory and attention

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María Del Carmen; Montañana i Aviñó, Antoni; Torres Cueco, Jorge; Sentieri Omarrementeria, Carla
- **Año:** 2020

- **Congreso:** International Conference on Innovation, Documentation and Education (INNODOCT/20)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-9048-873-7
- **Editorial:** Editorial Universitat Politècnica de València
- **Páginas:** 121 - 128

5.17. A virtual reality study in university classrooms: The influence of classroom colour on memory and attention

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María Del Carmen; Iñarra Abad, Susana; Serra Lluch, Juan
- **Año:** 2020
- **Congreso:** International Conference on Innovation, Documentation and Education (INNODOCT/20)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-9048-873-7
- **Editorial:** Editorial Universitat Politècnica de València
- **Páginas:** 129-136

5.18. Take a seat. The influence of distance to the blackboard on attention and memory performance

- **Autores:** Higuera-Trujillo, Juan Luis; Marí-Morales, Javier; Llinares Millán, María Del Carmen
- **Año:** 2021
- **Congreso:** 15th International Technology, Education and Development Conference (INTED2021)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-09-27666-0
- **Editorial:** IATED Academy
- **Páginas:** 7461 - 7465

5.19. The relationship between motivation and performance of university students

- **Autores:** Nolé, María Luisa; Higuera-Trujillo, Juan Luis; Marí-Morales, Javier; Llinares Millán, Carmen
- **Año:** 2021
- **Congreso:** 15th International Technology, Education and Development Conference (INTED2021)
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Tipo:** Artículo
- **ISSN:** 978-84-09-27666-0
- **Editorial:** IATED Academy
- **Páginas:** 7510 - 7515

6. Exposiciones / Exhibitions

6.1. Contribución de la Neuroarquitectura al diseño hospitalario

- **Autores:** Llinares Millán, Carmen; Guixeres Provinciale, Jaime; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan
- **Año:** 2014
- **Exposición:** EXCO 2014 / CEVISAMA – Feria Muestrario Internacional
- **Lugar:** Feria de Valencia
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.2. Ingeniería Kansei, Realidad Virtual y Medición Psicofisiológica para el diseño de espacios emocionalmente eficientes

- **Autores:** Llinares Millán, Carmen; Guixeres Provinciale, Jaime; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan
- **Año:** 2014
- **Exposición:** EXCO 2014 / CEVISAMA – Feria Muestrario Internacional
- **Lugar:** Feria de Valencia
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.3. Identificación de directrices de diseño para espacios de neonatología

- **Autores:** Higuera-Trujillo, Juan Luis; Montañana i Aviñó, Antoni; Llinares Millán, Carmen; López-Tarruella Maldonado, Juan; Guixeres Provinciale, Jaime; Iñarra Abad, Susana
- **Año:** 2015
- **Exposición:** EXCO 2015 / CEVISAMA – Feria Muestrario Internacional
- **Lugar:** Feria de Valencia
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.4. Diseño de espacios sanitarios mediante la aplicación de realidad virtual y medición psicofisiológica

- **Autores:** López-Tarruella Maldonado, Juan; Llinares Millán, Carmen; Juan; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana; Guixeres Provinciale, Jaime
- **Año:** 2015
- **Exposición:** EXCO 2015 / CEVISAMA – Feria Muestrario Internacional
- **Lugar:** Feria de Valencia
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.5. Una comparación de formatos de visualización arquitectónica: Su influencia en la orientación y la ayuda al proceso de diseño

- **Autores:** Higuera-Trujillo, Juan Luis; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen; Iñarra Abad, Susana; Montañana i Aviñó, Antoni
- **Año:** 2016
- **Exposición:** EXCO 2016 / CEVISAMA – Feria Muestrario Internacional
- **Lugar:** Valencia, España
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.6. EEG-index of stress generated by the environment: towards the neuroscience-based architectural design

- **Autores:** Higuera-Trujillo, Juan Luis; Marín Morales, Javier; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5

- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.7. NeuroArchitecture: prediction of emotional well-being provoked by spaces by indirect measurement of brain activity

- **Autores:** López-Tarruella Maldonado, Juan; Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Marín Morales, Javier
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5
- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.8. Development of new metrics to evaluate the impact of architecture on an emotional level in virtual environments

- **Autores:** Marín Morales, Javier; Higuera-Trujillo, Juan Luis; de Juan Ripoll, Carla; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5
- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.9. The 360º rendering as a tool for evaluating architectural spaces

- **Autores:** Iñarra Abad, Susana; Higuera-Trujillo, Juan Luis; Pistoni Pérez, Mario
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5
- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.10. Validation of Lighting Design trough the Emotional and Cognitive Effect of the Architectural Space

- **Autores:** Castilla-Cabanes, Nuria; Higuera-Trujillo, Juan Luis; Marín Morales, Javier; Llinares Millán, Carmen; López-Tarruella Maldonado, Juan
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5
- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.11. Emotional design: prediction of environmental color's effect in assessments of lactation rooms

- **Autores:** López-Tarruella Maldonado, Juan; Llinares Millán, Carmen; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana
- **Año:** 2017
- **Exposición:** EXCO 2017 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 5
- **Lugares:** Feria de Valencia / University of Basilicata / Silesian University of Technology / Odessa State Academy / Politecnico di Milano
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.12. Aplicación de la neurociencia al diseño en arquitectura

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Rojas-López, Juan Carlos
- **Año:** 2017
- **Exposición:** II Exposición de Jóvenes Arquitectos
- **Lugar:** Colegio Oficial de Arquitectos de Sevilla
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.13. El dibujo digital en arquitectura

- **Autores:** Higuera-Trujillo, Juan Luis; López-Tarruella Maldonado, Juan; Rojas-López, Juan Carlos
- **Año:** 2017
- **Exposición:** II Exposición de Jóvenes Arquitectos
- **Lugar:** Colegio Oficial de Arquitectos de Sevilla
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.14. Metodología para evaluar el impacto emocional de un espacio arquitectónico en escenarios virtuales

- **Autores:** Marín Morales, Javier; Higuera-Trujillo, Juan Luis; de Juan Ripoll, Carla; Iñarra Abad, Susana; López-Tarruella Maldonado, Juan; Llinares Millán, Carmen
- **Año:** 2017
- **Exposición:** II Exposición de Jóvenes Arquitectos
- **Lugar:** Colegio Oficial de Arquitectos de Sevilla
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.15. Neuroarquitectura: Nuevas herramientas para el diseño arquitectónico

- **Autores:** Higuera-Trujillo, Juan Luis
- **Año:** 2017
- **Exposición:** IV Encuentro de Estudiantes de Doctorado de la UPV
- **Lugar:** Universitat Politècnica de València
- **Ámbito:** Nacional
- **Contexto:** Colectiva

6.16. Neurociencia en la Arquitectura

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Alcañiz Raya, Mariano
- **Año:** 2017
- **Exposición:** III Jornadas Doctorales de la Universidad de Murcia

- **Lugar:** Universidad de Murcia
- **Ámbito:** Nacional
- **Contexto:** Colectiva

6.17. Mejorando el diseño mediante Neuroarquitectura

- **Autores:** Higuera-Trujillo, Juan Luis
- **Año:** 2018
- **Exposición:** V Encuentro de Estudiantes de Doctorado de la UPV
- **Lugar:** Universitat Politècnica de València
- **Ámbito:** Nacional
- **Contexto:** Colectiva

6.18. Methodological proposal to analyse pedestrian's safety perception in urban areas

- **Autores:** Llinares Millán, Carmen; Montañana i Aviñó, Antoni; Llorens Rodríguez, Roberto; Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; Iñarra Abad, Susana
- **Año:** 2018
- **Exposición:** EXCO 2018 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 6
- **Lugar:** Feria de Valencia / Politecnico di Milano / Silesian University of Technology / Odessa State Academy / Vilnius Gediminas Technical University / Universidad Tecnológica de La Habana
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.19. Emotion recognition in virtual environment: introducing an immersive virtual environment set

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; de Juan-Ripoll, Carla; Iñarra Abad, Susana;
Guixeres Provinciale, Jaime; Llinares Millán, Carmen
- **Año:** 2018
- **Exposición:** EXCO 2018 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 6
- **Lugar:** Feria de Valencia / Politecnico di Milano / Silesian University of Technology / Odessa State Academy / Vilnius Gediminas Technical University / Universidad Tecnológica de La Habana
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.20. Stress reduction in hospital waiting Rooms via visual, olfactory and auditory stimulus. Psychological and neurophysiological measurement

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen; Montañana i Aviñó, Antoni
- **Año:** 2018
- **Exposición:** EXCO 2018 / CEVISAMA – Feria Muestrario Internacional
- Itinerancias: 6
- **Lugar:** Feria de Valencia / Politecnico di Milano / Silesian University of Technology / Odessa State Academy / Vilnius Gediminas Technical University / Universidad Tecnológica de La Habana
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.21. Validation of the environmental simulation systems through psychological and physiological measurement

- **Autores:** Higuera-Trujillo, Juan Luis; López-Tarruella, Juan; Llinares Millán, Carmen; Rojas, Juan-Carlos
- **Año:** 2018
- **Exposición:** EXCO 2018 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 6
- **Lugar:** Feria de Valencia / Politecnico di Milano / Silesian University of Technology / Odessa State Academy / Vilnius Gediminas Technical University / Universidad Tecnológica de La Habana
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.22. Implications in the students' memory of the university classroom colour

- **Autores:** Higuera-Trujillo, Juan Luis; Serra Lluch, Juan; Marín-Morales, Javier; Llinares Millán, Carmen
- **Año:** 2019
- **Exposición:** EXCO 2019 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 10
- **Lugar:** Feria de Valencia / Beijing Yong Shan Media Co. / Silesian University of Technology / Politecnico di Milano / Università degli Studi di Salerno / Mimar Sinan Fine Arts University / Odessa State Academy / Ex Ospedale di San Rocco – Chiesa di Cristo Flagellato / Vilnius Gediminas Technical University /
Jade Hochschule University of Applied Sciences
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.23. Incidence of the university classroom space in student's attention

- **Autores:** Llinares Millán, Carmen; Montañana i Aviñó, Antoni; Higuera-Trujillo, Juan Luis; Torres Cueco, Jorge; Sentieri Omarrementeria, Carla
- **Año:** 2019
- **Exposición:** EXCO 2019 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 10
- **Lugar:** Feria de Valencia / Beijing Yong Shan Media Co. / Silesian University of Technology / Politecnico di Milano / Università degli Studi di Salerno / Mimar Sinan Fine Arts University / Odessa State Academy / Ex Ospedale di San Rocco – Chiesa di Cristo Flagellato / Vilnius Gediminas Technical University /
Jade Hochschule University of Applied Sciences
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.24. Incidence of vegetation, sidewalk size and artificial lighting on the perceived sense of safety of pedestriansover 65 years

- **Autores:** Llinares Millán, Carmen; Higuera-Trujillo, Juan Luis; Montañana i Aviñó, Antoni; Castilla-Cabanes, Nuria; Marín-Morales, Javier; Llorens Rodríguez, Roberto
- **Año:** 2019
- **Exposición:** EXCO 2019 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 10

- **Lugar:** Feria de Valencia / Beijing Yong Shan Media Co. / Silesian University of Technology / Politecnico di Milano / Università degli Studi di Salerno / Mimar Sinan Fine Arts University / Odessa State Academy / Ex Ospedale di San Rocco – Chiesa di Cristo Flagellato / Vilnius Gediminas Technical University / Jade Hochschule University of Applied Sciences
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.25. Dominance emotion recognition using physiological responses in immersive urban virtual environments

- **Autores:** Marín-Morales, Javier; Higuera-Trujillo, Juan Luis; Llinares Millán, Carmen
- **Año:** 2019
- **Exposición:** EXCO 2019 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 10
- **Lugar:** Feria de Valencia / Beijing Yong Shan Media Co. / Silesian University of Technology / Politecnico di Milano / Università degli Studi di Salerno / Mimar Sinan Fine Arts University / Odessa State Academy / Ex Ospedale di San Rocco – Chiesa di Cristo Flagellato / Vilnius Gediminas Technical University / Jade Hochschule University of Applied Sciences
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.26. Validation of a virtual classroom for assessment of cognitive functioning: use of neurophysiological metrics within a real and virtual space

- **Autores:** Higuera-Trujillo, Juan Luis; Llinares Millán, María Del Carmen; Calabuig Valls, Francisco
- **Año:** 2020
- **Exposición:** EXCO 2020 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 8
- **Lugar:** Feria de Valencia / Odesa State Academy of Civil Engineering and Architecture / Mimar Sinan Fine Arts University / Università degli Studi di Salerno / Jade Hochschule University of Applied Sciences / Politecnico di Milano / Silesian University of Technology / Beijing Yong Shan Media Co. / University degli Studi della Basilicata
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.27. Does the tone of the classroom (warm vs cold) influence the student's memory? A psychophysiological analysis

- **Autores:** Llinares Millán, María Del Carmen; Higuera-Trujillo, Juan Luis; Serra Lluch, Juan; Iñarra Abad, Susana
- **Año:** 2020
- **Exposición:** EXCO 2020 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 8
- **Lugar:** Feria de Valencia / Odesa State Academy of Civil Engineering and Architecture / Mimar Sinan Fine Arts University / Università degli Studi di Salerno / Jade Hochschule University of Applied Sciences / Politecnico di Milano / Silesian University of Technology / Beijing Yong Shan Media Co. / University degli Studi della Basilicata
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.28. Neuropsychophysiological effects of classroom illuminance on higher education student's attention

- **Autores:** Llinares Millán, María Del Carmen; Higuera-Trujillo, Juan Luis; Castilla Cabananes, Nuria
- **Año:** 2020
- **Exposición:** EXCO 2020 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 8
- **Lugar:** Feria de Valencia / Odesa State Academy of Civil Engineering and Architecture / Mimar Sinan Fine Arts University / Università degli Studi di Salerno / Jade Hochschule University of Applied Sciences / Politecnico di Milano / Silesian University of Technology / Beijing Yong Shan Media Co. / University degli Studi della Basilicata
- **Ámbito:** Internacional
- **Contexto:** Colectiva

6.29. Improving student's attention through the height of the classroom ceiling. An application of neuroarchitecture

- **Autores:** Llinares Millán, María Del Carmen; Torres Cueco, Jorge; Higuera-Trujillo, Juan Luis; Sentieri Omarrementeria, Carla; Montañana i Aviñó, Antoni
- **Año:** 2020
- **Exposición:** EXCO 2020 / CEVISAMA – Feria Muestrario Internacional
- **Itinerancias:** 8
- **Lugar:** Feria de Valencia / Odesa State Academy of Civil Engineering and Architecture / Mimar Sinan Fine Arts University / Università degli Studi di Salerno / Jade Hochschule University of Applied Sciences / Politecnico di Milano / Silesian University of Technology / Beijing Yong Shan Media Co. / University degli Studi della Basilicata
- **Ámbito:** Internacional
- **Contexto:** Colectiva

7. Premios / Awards

7.1. Seleccionado entre las diez mejores presentaciones en formato póster del "IV Encuentro de Estudiantes de Doctorado de la UPV"

- **Entidad:** Universitat Politècnica de València
- **Fecha:** 01/06/2017

7.2. Seleccionado entre las diez mejores presentaciones en formato póster del "V Encuentro de Estudiantes de Doctorado de la UPV"

- **Entidad:** Universitat Politècnica de València
- **Fecha:** 05/07/2018

7.3. Seleccionado como mejor presentación en el "8th International Conference on Innovation, Documentation and Teaching Technologies"

- **Entidad:** INNOCOT - Universitat Politècnica de València
- **Fecha:** 12/11/2020

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Los humanos respondemos cognitiva y emocionalmente a la arquitectura. Por lo tanto, su diseño también debe satisfacer este tipo de necesidades. Tradicionalmente, la idea ha sido foco de reflexiones e investigaciones; no siempre abordadas a través de la propia arquitectura, sino mediante otras aproximaciones. Entre ellas: la geometría, la fenomenología del espacio, la geografía de la experiencia, la filosofía, y la psicología; cada una con sus metodologías de carácter cuantitativo o cualitativo. De manera más reciente, han surgido nuevas aproximaciones con la incorporación de la realidad virtual (con sus tecnologías aplicadas, permite generar experiencias arquitectónicas comparables a las físicas) y la neurociencia (con sus tecnologías aplicadas, permite un registro objetivo de la experiencia cognitiva y emocional). Sin embargo, sus potenciales en este ámbito de estudio no han sido suficientemente explorados. El objetivo de la presente Tesis Doctoral es contribuir en la investigación y diseño de la dimensión cognitivo-emocional de la arquitectura, a nivel teórico y práctico. A nivel teórico implicó una revisión bibliográfica, contextualizada y crítica, sobre el estudio cognitivo-emocional de la arquitectura desde una perspectiva amplia, considerando el conjunto de aproximaciones. A nivel práctico, se abordaron ambas aproximaciones. En cuanto a las tradicionales, la finalidad fue explorar los beneficios de combinar las metodologías cuantitativas y cualitativas más usualmente empleadas. En cuanto a las nuevas, la finalidad fue validar el uso de los actuales sistemas de simulación ambiental y examinar su uso combinado con los sistemas de registro neurofisiológico.

Humans respond cognitively and emotionally to architecture. Therefore, its design should also meet these kinds of needs. The issue has not always been approached from a solely architectural perspective; it has also been examined based on other disciplinary foundations. These include: geometry, the phenomenology of space, geographical experience, philosophy and psychology; approach has its methodologies, quantitative or qualitative in nature. More recently, new approaches have emerged with the integration of virtual reality (with its applied technologies, it allows the generation of architectural experiences comparable to physical ones) and neuroscience (with its applied technologies, it allows an objective record of cognitive and emotional experience). However, their potential in this field of study has not been sufficiently explored. The aim of this Doctoral Thesis is to contribute to the research and design of the cognitive-emotional dimension of architecture, on a theoretical and practical level. On a theoretical level, it involved a contextualised and critical bibliographical review of the cognitive-emotional study of architecture from a broad perspective, considering the set of approaches. On a practical level, both approaches were addressed. With regard to base approaches, the aim was to explore the benefits of combining the most commonly used quantitative and qualitative methodologies. With regard to new approaches, the aim was to validate the use of existing environmental simulation systems and to examine their use in combination with neurophysiological recording systems.