UNIVERSIDAD POLITÉCNICA DE MADRID

ESCUELA TÉCNICA SUPERIOR DE ARQUITECTURA DE MADRID

MEJORA CUANTITATIVA DE LAS PRESTACIONES DE LOS
ESPACIOS DE TRABAJO. EMPLEO DE VEGETACIÓN, LUZ
NATURAL Y MADERA

THE QUANTITATIVE IMPROVEMENTS OF THE CAPABILITIES
OF WORKPLACES. THE USE OF GREENERY,
DAYLIGHT AND WOOD

TESIS DOCTORAL

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Arquitecta

2019

DEPARTAMENTO DE CONSTRUCCIÓN Y TECNOLOGÍA ARQUITECTÓNICA

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2019

POLITÉCNICA

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AGRADECIMIENTOS

En primer lugar, gracias a todas las personas que han participado en esta investigación, y a todos aquellos que me han dado fuerza durante todo este proceso. En especial a Daniel por su amor y su paciencia infinitos.

Gracias al Profesor Dr. Toshiharu Ikaga y a todos los miembros de su laboratorio por enseñarme tanto y permitir mi estancia de dos años en su maravilloso laboratorio en la Universidad de Keio, Japón.

Agradecer a la Universidad Politécnica de Madrid y al Profesor Dr. Sergio Vega Sánchez, director de esta Tesis Doctoral, por su soporte en la elaboración de esta investigación. Gracias al Profesor Dr. Federico García Erviti por su consejo siempre tan oportuno.

Mi agradecimiento al programa Erasmus Mundus EASED (Grant 2012-5538/004-001) coordinado por Centrale Supelec, que ha financiado mi estancia predoctoral en la Universidad de Keio.

Gracias a CB Richard Ellis y a todos mis compañeros en esta empresa, por su confianza y colaboración.

Por último, y más importante, gracias a mis padres, Alfonso y Maribel, porque sin ellos nada de esto habría sucedido.

A mis padres

ÍNDICE

RESUMEN DE TESIS

CAPITULO I – INTRODUCCION, OBJETIVOS, HIPOTESIS Y DESARROLLO

1. Introducción y Justificación
2. Hipótesis de trabajo
3. Objetivos principales y secundarios
4. Mapa de procesos y esquema de desarrollo de tesis

CAPITULO II – REVISIÓN DEL ESTADO DEL ARTE

1. Antecedentes
2. Conceptos clave
  - 2.1. Concepto I. Productividad
  - 2.2. Concepto II. Biofilia
  - 2.3. Concepto III. Experimento Piloto
3. Espacios de Trabajo
  - 3.1. Recorrido Histórico
  - 3.2. Conceptos
    - 3.2.1. Concepto I. Espacio
    - 3.2.2. Concepto II. Procesos
    - 3.2.3. Concepto III. Espacio, procesos y personas
4. Salud, bienestar y productividad
  - 4.1. Síndrome del Edificio Enfermo
  - 4.2. La relación entre salud, bienestar y productividad
5. Análisis cualitativo de Casos de Estudio. Japón (texto en inglés)
6. Análisis cualitativo de Casos de Estudio. Australia (texto en inglés)
7. Comunidad científica
8. Conclusiones

CAPITULO III – LA HERRAMIENTA

1. Fase 0: Kick-off
  - 1.1. Concepto
  - 1.2. Matriz RACI
  - 1.3. Hipótesis de cada experimento piloto
2. Fase 1: Diseño del experimento piloto
  - 2.1. Selección de personas participantes
  - 2.2. Caracterización de variables
  - 2.3. Creación de escenario de control y escenarios experimentales
  - 2.4. Selección de mediciones a realizar
  - 2.5. Definición de programación temporal
3. Fase 2: Ejecución del experimento piloto
  - 3.1. Calibrado de equipos
  - 3.2. Formación previa
  - 3.3. Toma de muestras
4. Fase 3: Análisis de datos y conclusiones
  - 4.1. Procesado de datos y análisis
  - 4.2. Aplicación de métodos estadísticos
  - 4.3. Establecimiento de resultados, discusión y conclusiones

CAPITULO IV – CASOS DE ESTUDIO (texto en inglés)

1. Caso de Estudio 1
  - 1.1. Resumen
  - 1.2. Introducción
  - 1.3. Objetivos
  - 1.4. Herramienta
  - 1.5. Evaluación del Experimento Piloto
    - 1.5.1. Evaluación ambiental
    - 1.5.2. Evaluación fisiológica
    - 1.5.3. Evaluación psicológica
      - 1.5.3.1. Método de cuestionarios. Evaluación subjetiva

- 1.5.3.2. Método de cuestionarios. Jikaku-sho Shirabe
    - 1.5.3.3. Método de cuestionarios. National aeronautics and space administration-task load index (NASA-TLX)
  - 1.5.4. Métodos Estadísticos
  - 1.5.5. Contenido del trabajo simulado
- 1.6. Resultados
- 1.7. Discusión de los resultados
- 1.8. Conclusiones
- 2. Caso de Estudio 2
  - 2.1. Resumen
  - 2.2. Introducción
  - 2.3. Objetivos
  - 2.4. Herramienta
  - 2.5. Evaluación del Experimento Piloto
    - 2.5.1. Evaluación ambiental
    - 2.5.2. Evaluación fisiológica
    - 2.5.3. Evaluación psicológica
    - 2.5.4. Métodos Estadísticos
    - 2.5.5. Contenido del trabajo simulado
  - 2.6. Resultados
  - 2.7. Discusión de los resultados
  - 2.8. Conclusiones
- 3. Caso de Estudio 3
  - 3.1. Introducción
  - 3.2. Objetivos
  - 3.3. Herramienta
  - 3.4. Evaluación del Experimento Piloto
    - 3.4.1. Evaluación ambiental
    - 3.4.2. Evaluación fisiológica
    - 3.4.3. Evaluación psicológica

3.4.4. Evaluación de la productividad a través de la capacidad cognitiva

3.4.5. Evaluación de la creatividad a través del método de taxonomía del pensamiento creativo

3.4.6. Ejercicio físico y meditación

3.4.7. Formación a través de la gestión del cambio

3.4.8. Métodos Estadísticos

3.5. Resultados y discusión

3.6. Conclusiones

CAPITULO V – CONCLUSIONES (texto en español e inglés)

1. Análisis e interpretación de los resultados
2. Conclusión final
3. Optimización de la herramienta y futuras líneas de investigación

INDICE DE ILUSTRACIONES

INDICE DE TABLAS

BIBLIOGRAFÍA

ANEXOS

1. Anexo I. Recopilación de datos del Caso de Estudio I
2. Anexo II. Recopilación de datos del Caso de Estudio II

INDEX

THESIS ABSTRACT

CHAPTER I – INTRODUCTION, OBJETIVES, HYPOTHESIS AND DEVELOPMENT

1. Introduction and Justification
2. Work Hypothesis
3. Main and secondary objectives
4. Process map and thesis development scheme

CHAPTER II – LITERATURE REVIEW

1. Background
2. Key concepts
  - 2.1. Concept I. Productivity
  - 2.2. Concept II. Biophilia
  - 2.3. Concept III. Pilot experiment
3. Workplaces
  - 3.1. History
  - 3.2. Concepts
    - 3.2.1. Concept I. Space
    - 3.2.2. Concept II. Processes
    - 3.2.3. Concept III. Spaces, processes and people
4. Health, well-being and productivity
  - 4.1. Sick Building Syndrome
  - 4.2. The relationship between Health, well-being and productivity
5. Scenario studies qualitative analysis. Japan
6. Scenario studies qualitative analysis. Australia
7. Scientific community
8. Conclusions

CHAPTER III –THE TOOL

1. Phase 0: Kick-off
  - 1.1. Concept
  - 1.2. RACI matrix
  - 1.3. Hypotheses for each pilot experiment
2. Phase 1: Pilot Experiment Design
  - 2.1. Selection of the participants
  - 2.2. Characterization of variables
  - 2.3. Creation of control scenarios and experimental scenarios
  - 2.4. Selection of measurements to be carried out
  - 2.5. Schedule definition
3. Phase 2: Pilot Experiment Execution
  - 3.1. Calibration of equipment
  - 3.2. Previous training
  - 3.3. Sample collection
4. Phase 3: Data analysis and conclusions
  - 4.1. Data processing and analysis
  - 4.2. Application of statistical methods
  - 4.3. Establishment of results, discussion and conclusions

CHAPTER IV –SCENARIO STUDIES

1. Case Study 1
  - 1.1. Abstract
  - 1.2. Introduction
  - 1.3. Objectives
  - 1.4. Tool
  - 1.5. Pilot experiment assessment
    - 1.5.1. Environmental assessment
    - 1.5.2. Physiological assessment
    - 1.5.3. Psychological assessment
      - 1.5.3.1. Questionnaires method. Subjective assessment

- 1.5.3.2. Questionnaires method. Jikaku-sho Shirabe
    - 1.5.3.3. Questionnaires method. National aeronautics and space administration-task load index (NASA-TLX)
  - 1.5.4. Statistical methods
  - 1.5.5. Simulated work tasks
- 1.6. Results
- 1.7. Discussion of the results
- 1.8. Conclusions
- 2. Case Study 2
  - 2.1. Abstract
  - 2.2. Introduction
  - 2.3. Objectives
  - 2.4. Tool
  - 2.5. Pilot experiment assessment
    - 2.5.1. Environmental assessment
    - 2.5.2. Physiological assessment
    - 2.5.3. Psychological assessment
    - 2.5.4. Statistical methods
    - 2.5.5. Simulated work tasks
  - 2.6. Results
  - 2.7. Discussion of the results
  - 2.8. Conclusions
- 3. Case Study 3
  - 3.1. Introduction
  - 3.2. Objectives
  - 3.3. Tool
  - 3.4. Pilot Experiment Assessment
    - 3.4.1. Environmental assessment
    - 3.4.2. Physiological assessment
    - 3.4.3. Psychological assessment
    - 3.4.4. Productivity assessment

- 3.4.5. Creativity assessment
- 3.4.6. Physical activity and meditation
- 3.4.7. Training through change management
- 3.4.8. Statistical methods
- 3.5. Results and discussion
- 3.6. Conclusions

CHAPTER V – CONCLUSIONS

- 1. Analysis and interpretation of the results
- 2. Final conclusion
- 3. Optimization of the tool and future lines of research

BIBLIOGRAPHY

INDEX OF ILLUSTRATIONS

INDEX OF TABLES

BIBLIOGRAPHY

ANNEXES

- 1. Annex I. Case Study I Data Collection
- 2. Annex II. Case Study II Data Collection

RESUMEN

Numerosos estudios respaldados por la comunidad científica afirman que el diseño del espacio de trabajo puede contribuir a la mejora de la productividad y el bienestar de los usuarios. Sin embargo, es necesario ir un paso más allá y objetivar los criterios que actúan impulsando el aumento la productividad y el bienestar en la práctica del diseño arquitectónico. En respuesta a los desafíos de cómo medir el aumento de la productividad y el bienestar a través del diseño arquitectónico, la principal contribución de esta Tesis es el desarrollo de una herramienta que permite medir las características que pueden mejorar la productividad y el bienestar, basada en un método científico, mediante una aproximación holística de los factores fisiológicos, psicológicos, emocionales y culturales que influyen en la productividad y bienestar de las personas, y que se comprueba mediante la realización de tres experimentos piloto.

Se llevaron a cabo tres experimentos piloto previamente programados, como una versión a pequeña escala realizada en preparación para un estudio mayor, con el objetivo de comprobar una herramienta que cuantifica el impacto de las características de diseño en el aumento de la productividad y el bienestar, evaluando la influencia de variables tangibles e intangibles en el espacio de trabajo, y permitiendo así el análisis del conocimiento sobre diseño del espacio de trabajo en una mayor profundidad.

Simultáneamente, el papel del diseño biofílico en ambientes interiores, entendido como espacios en el interior de edificios provistos de elementos de la naturaleza, ha recibido relativamente poca atención, en comparación con el número de estudios que evalúan el impacto relacionado con otras características de los ambientes interiores como los derivados de sistemas eléctricos y mecánicos, de factores térmicos, ruido y vibraciones, ergonomía y diseño de oficinas. El presente estudio es uno de los primeros estudios que evalúan y miden la combinación de variables relacionadas con propuestas de diseño biofílico. Los resultados destacan una mejora en el bienestar, la productividad, la creatividad y la salud al introducir características biofílicas en el diseño del espacio de trabajo. La herramienta desarrollada y probada en estos experimentos piloto constituye una nueva vía para aumentar la productividad en el espacio de trabajo, en contraste con la práctica existente.

Palabras clave: Espacio de trabajo, productividad, salud, bienestar, Biofilia, experimento piloto

ABSTRACT

Numerous studies endorsed by the scientific community state that workplace design can contribute to an improvement in the productivity and well-being of the users. However, it is necessary to go a step further and objectify the criteria that increase productivity and well-being in the practice of architectural design. The main contribution of this Thesis is the development of a tool that responds to the challenges of how to measure the increase in productivity and well-being through architectural design. The proposed tool allows us to measure the characteristics that can improve productivity and well-being, based on a scientific method, and through a holistic approach of the physiological, psychological, emotional and cultural factors that impact on productivity and well-being of the users. The tool is ascertained through the implementation of three pilot experiments.

To verify a tool that quantifies the impact of design features on the increase of productivity and well-being, three previously programmed pilot experiments were carried out, such as a small-scale version conducted in preparation for a major study. These Scenarios studies evaluated the impact of tangible and intangible variables on the workplace, thus allowing for the in-depth analysis of workplace design knowledge.

Simultaneously, the role of biophilic design in indoor environments - defined as spaces within buildings featuring natural elements - has received relatively little attention, compared to the number of studies evaluating the impact of other indoor environment characteristics of the buildings related with electrical and mechanical systems, thermal factors, noise and vibrations, ergonomics and office fit-outs. The present study is one of the first studies to evaluate and measure the combination of variables concerning biophilic design proposals. The results highlight an improvement in well-being, productivity, creativity and health by introducing biophilic characteristics into workplace design. The tool developed and tested in these pilot experiments opens up a path to increase productivity in the workplace in contrast to existing practices.

Keywords: Workplace, Performance, Health, Well-being, Biophilia, Pilot experiment

C.I. INTRODUCCION, HIPÓTESIS, OBJETIVOS Y DESARROLLO

En este capítulo se justifica el interés del tema de investigación, se establece la hipótesis de trabajo, los objetivos principales y secundarios y se explica el flujograma de trabajo seguido en la presente investigación

1.INTRODUCCIÓN Y JUSTIFICACIÓN

La oficina no es sólo un lugar donde desarrollar una actividad profesional, sino que constituye un factor competitivo que aporta valor diferencial. La oficina o espacio corporativo es además el escenario en el que se generan los éxitos de una organización, y un medio de comunicación a través del cual se reflejan y difunden, tanto de manera interna como externa, los valores que definen a la organización [10], [12], [13].

Toda organización empresarial se enfrenta a una serie de desafíos: el cambiante mundo de los espacios de trabajo, los avances tecnológicos, las fluctuaciones extremas de los ciclos económicos, la creciente globalización, el aumento de los costes y el difuso límite entre la vida laboral y personal. En la actualidad, la viabilidad económica de los espacios de trabajo y la respuesta a los desafíos planteados está compuesta por una relación compleja de factores de éxito. Por un lado, factores que denominamos "blandos", como innovación, agilidad, atractivo de la organización, retención de talento, sostenibilidad y responsabilidad social de las organizaciones. Por otro lado, factores que denominamos "duros": el coste de personal y de bienes inmobiliarios y el equilibrio entre ambos [2], [7], [10].

Existen estudios que cuantifican las pérdidas o ganancias en organizaciones de hasta el 15% del volumen de negocios, siendo estas atribuibles al diseño, la gestión, al uso y a la correcta explotación del mismo [87]. Las grandes organizaciones han tomado conciencia de ello y miden la repercusión de sus gastos. Según estudios, el índice de coste por trabajador con jornada completa de la Unión Europea es de 9.853 € y de España, 7.141 € [169].

Según AOS STUDLEY [129], el dato de índice de coste por ocupante OCI (Occupier Cost Index), representa el coste medio anual por trabajador a jornada completa del año 2013. El resultado ha sido compilado analizando una base de datos de 22 países europeos, 3.400 edificios de oficinas, 31 millones de metros cuadrados y representando a más de 1.45 millones de empleados con jornada completa.

El papel de los profesionales de la edificación se encuentra en proceso de cambio desde el momento en que las organizaciones son conscientes de los resultados económicos y sociolaborales que conlleva medir la repercusión del uso de los espacios de trabajo y la satisfacción de usuarios. Esto se convierte en un campo de conocimiento reconocido. Aparece un nuevo “profesionalismo” ligado a la cultura organizativa de las empresas, alineado a las necesidades empresariales y que establece las bases para tender un puente entre el diseño, la ejecución del proyecto y la explotación de la actividad de una manera sostenible [91].

En este contexto, la mejora de la productividad y el bienestar es clave, y se puede influir desde el espacio arquitectónico. Sabemos que los edificios sostenibles mejoran la productividad y bienestar de las personas [12], [17], [76], [93]. Sin embargo, la mejora no está objetivada y cuantificada.

2. HIPÓTESIS DE TRABAJO

Esta investigación surge del interés por los espacios de trabajo y cómo influyen en el bienestar y la productividad de las personas, y su drástica evolución a lo largo del tiempo. Sin embargo, la primera parte de esta investigación, consistente en recorrer buena parte del mundo en busca de casos de estudio de edificios de oficinas, ha permitido a la doctoranda constatar que todavía la amplia mayoría de empresas no cuentan con diseños de oficinas enfocados a aumentar el bienestar de las personas. Esto se debe en parte a que no existe un método de medición que nos permita comparar el impacto del espacio en los empleados, su aumento en productividad y por tanto calcular el retorno que tiene invertir en un espacio de trabajo excelente.

En base a lo anteriormente descrito, se puede establecer la hipótesis de que a través de una metodología adecuada podría crearse una herramienta que permitiera comparar entornos de trabajo, cuantificando la diferencia en métricas arrojadas por los usuarios relativas a productividad y bienestar. De este modo, sería posible identificar las variables de los entornos que tienen una mayor incidencia en las variaciones de los resultados.

Por tanto, la hipótesis de la que parte la presente tesis es que una herramienta adecuada puede permitir medir, y por tanto mejorar, la productividad y bienestar de los usuarios en los espacios de trabajo con múltiples variables tangibles e intangibles que pueden ser caracterizadas.

3.OBJETIVOS PRINCIPALES Y SECUNDARIOS

El objetivo principal de esta tesis es desarrollar una herramienta que nos permita medir de manera objetiva la mejora de productividad y bienestar en los entornos de trabajo, a través de parámetros fisiológicos, psicológicos, emocionales y culturales. Esta herramienta será flexible, de manera que pueda adaptarse a las variables que forman parte del entorno escogido, y a los factores que se quieren cuantificar.

Las variables son aquellos aspectos que forman parte del entorno de trabajo, y cuyo impacto se quiere cuantificar. Algunos ejemplos de variables típicas de estudio podrían ser: temperatura en el espacio de trabajo, grado de iluminación, acústica y nivel sonoro en el espacio de trabajo, etc.

Los factores a cuantificar son aquellos que interesan en cada caso de estudio y a cada corporación, tales como: productividad, creatividad, nivel de estrés, calidad del sueño, capacidad de atención, motivación, etc.

Se definen además los siguientes objetivos secundarios:

- Identificar qué variables tienen un mayor impacto en la experiencia del usuario. Siguiendo la definición de experiencia del usuario de Massie, se obtiene que la experiencia de usuario engloba todos los aspectos de la interacción del usuario con la compañía, sus servicios y sus productos. Es decir, no sólo consiste en la experiencia del usuario con el espacio arquitectónico, sino la experiencia que tiene con cualquier contacto que realiza con la compañía [96].

- Según diversos autores, la mala calidad del sueño es el problema de salud más frecuente entre la población de los países desarrollados, por delante de problemas como la obesidad, tabaquismo, alcoholismo o sedentarismo [127], [26]. Por consiguiente, en la presente investigación se analiza específicamente el impacto de los entornos de trabajo en la calidad del sueño.
- La herramienta propuesta utiliza parámetros fisiológicos, pero también psicológicos y emocionales. En ocasiones, se observa que ciertas reacciones fisiológicas se contradicen con respuestas emocionales y psicológicas. Por este motivo, se plantea como un objetivo adicional específico el analizar el efecto psicológico de algunas variables, que no tienen un efecto real (fisiológico) pero sí percibido [17], [166].

4. MAPA DE PROCESOS Y ESQUEMA DE DESARROLLO DE TESIS

El mapa de proceso de desarrollo de la presente investigación se ilustra en la Figura 1. Éste surge a partir de los retos planteados sobre cómo aumentar la productividad y el bienestar a través del diseño arquitectónico, y cómo medir dicho aumento.

Como respuesta a los retos planteados, se establece una hipótesis de partida. El desarrollo de la herramienta de medición constituye la principal aportación de esta Tesis Doctoral, y se testea a través de tres casos de estudio. Finalmente, se concluye validando o refutando la hipótesis inicial, así como obteniendo conclusiones parciales derivadas de los casos de estudio específicos y conclusiones específicas sobre la herramienta propuesta.

Figura 1. Mapa de Proceso de desarrollo de la presente investigación.

En cuanto al esquema de desarrollo seguido en esta Tesis Doctoral, a continuación, se expone el cronograma y fases que lo conforman.

Respecto al cronograma, la investigación se inicia en el año 2013, estableciendo el tema de investigación y comenzando con el análisis del Estado del Arte.

La primera parte del análisis del Estado del Arte consistió en viajar en búsqueda de casos de estudio de interés relacionados con entornos de trabajo. Este viaje estuvo compuesto por una estancia de dos años de duración en Japón, una estancia de tres meses de duración en Australia, y un recorrido total de aproximadamente un año, repartido en intervalos, visitando casos de estudio de países en Europa, América, Asia y Oceanía. Algunos de estos países fueron Estados Unidos, Hong Kong, Singapur, Nueva Zelanda, Alemania, Austria y Reino Unido.

La segunda parte del análisis del Estado del Arte está constituida por el estudio sistemático de la historia de los entornos de trabajo a lo largo de la historia, así como factores relevantes relacionados con entornos de trabajo. El conocimiento desprendido por las dos partes que componen el análisis del Estado del Arte, basadas en experiencia propia de la doctoranda y en el estudio teórico de la literatura relevante para el tema de investigación, se reflejan en el presente documento, y nutren a la herramienta propuesta y al planteamiento de la investigación.

Tras la búsqueda y análisis del Estado del Arte, se desarrolla la Herramienta que constituye la principal aportación de esta Tesis, comprobada mediante tres casos de estudio, correspondientes a tres experimentos piloto, realizados en Japón y España. De cada uno de estos tres casos de estudio se redacta una publicación para revista científica, destacando uno de ellos que ha sido publicado con fecha trece de agosto de dos mil dieciocho en la revista Energy & Buildings clasificada dentro del primer cuartil del Journal Citation Report Index [8].

Después de la realización de los tres casos de estudio, que inicia en 2016 y concluye en 2018, se procede a la discusión y extracción de conclusiones conjuntas. Por último, se redacta el presente documento de Tesis cuya lectura se produce en abril de 2019. La Figura 2 ilustra el cronograma descrito.

Figura 2. Cronograma de la investigación.

El desarrollo de esta tesis se divide en seis fases, las cuales se detallan en los siguientes párrafos.

En primer lugar, se establecen la hipótesis y objetivos especificados en el apartado 2.3 del Capítulo I, basado en la hipótesis de que una herramienta adecuada permitirá mejorar la productividad, y por tanto el objetivo es desarrollar dicha herramienta.

Segundo, se analiza el Estado del Arte, aspectos teóricos y fundamentación, métodos existentes de cuantificación de la mejora de la productividad y se estudian ejemplos reales en diversos países, destacando España y Japón y Australia.

En tercer lugar, se define y desarrolla la herramienta integrada para la cuantificación objetiva de mejora de la productividad y bienestar.

El cuarto punto corresponde a la aplicación experimental, detallándose tres casos de estudio realizados en Japón y España.

En quinto lugar, se establecen las conclusiones, destacando la conclusión contrastada con la hipótesis inicial. Asimismo, se indican líneas de optimización de la herramienta y líneas de investigación futura.

En sexto y último lugar, se referencian actividades y otros méritos paralelos al desarrollo de esta Tesis, como la aplicación de la investigación en una empresa del sector inmobiliario y la participación de la doctoranda en diversos congresos y ponencias [9], [10].

C.II. REVISIÓN DEL ESTADO DEL ARTE

Este capítulo presenta un análisis y descripción de los diferentes tipos de espacios de oficinas desarrollados, así como una evaluación del potencial de los factores de éxito detectados en los nuevos espacios, y la relación entre salud, bienestar y productividad en espacios de oficinas. Esta descripción se ilustra con el análisis cualitativo de diversos casos de estudio en Japón y Australia. Finalmente, se presenta la comunidad científica que está investigando este mismo tema.

1. ANTECEDENTES

Las oficinas que conocemos hoy en día tienen detrás una larga historia de evolución. La oficina como lugar de trabajo ha existido desde que las personas se asentaron en un lugar y necesitaron un sitio donde solucionar sus asuntos de negocios [132].

Empezando por ejemplos tempranos, como podría ser el Uffizi en Florencia, que originalmente era un edificio administrativo, el concepto de oficina se ha ido definiendo y concretando a lo largo de los siglos.

Actualmente, este esquema único de oficina ha empezado a diluirse en favor de nuevas tendencias, que se apoyan en conceptos y neologismos, a partir de las cuales han surgido nuevas tipologías de oficinas [12], [37], [48].

El concepto de espacio en las oficinas evoluciona adaptándose al cambio y a los diferentes hitos evolutivos ligados a la historia, cultura (organizacional y social), tecnología de la edificación y de las nuevas herramientas de trabajo [19], [37], [75].

Las nuevas tecnologías de información y comunicación (TIC) supondrán un nuevo reto para la evolución de los espacios. Todos estos cambios aparecen bajo las etiquetas de “Flexible Workplace”, “Mobile Worker”, “Information and Knowledge Worker”, “Social networking”, etc [20], [74], [75].

Más allá de los límites confinados por las luchas sindicales de los siglos XIX y XX las relaciones personales empiezan a colonizar tiempos en los espacios de trabajo y viceversa, en una especie de *quid pro quo*. Las organizaciones se verán obligadas a ceder tiempos para que la vida en común pueda seguir su curso [14], [19].

La jornada fija laboral se encuentra difuminada. La movilidad y la conectividad de los profesionales se ha convertido en una característica más allá del concepto de teletrabajo [14].

Los jóvenes son un sector rápidamente sintonizado con estos cambios. El uso que realizan de su tiempo con las TIC promueve su relación personal. Ellos son los futuros trabajadores en formación que configurarán una nueva sociedad flexible, conectada, global e informacional y marcarán el mundo sociolaboral [14].

2. CONCEPTOS CLAVE

2.1 Concepto I. Productividad.

Existen numerosas formas de definir el término “productividad”, que en el contexto de los espacios de trabajo también se identifica como “rendimientos en las tareas”.

La productividad generalmente mide cantidad: cuánto trabajo es realizado y entregado en forma de productos y servicios (inputs y outputs) y cómo de eficientemente [106].

La calidad del trabajo también es importante y en algunos casos puede incluir indicadores fácilmente identificables como errores, número de repetición de tareas, y trabajo completado dentro de plazo.

Para algunos tipos de trabajo muy cualificado, estos tipos de mediciones son más complejas, ya que el impacto de este tipo de trabajo no se puede demostrar de manera inmediata y no siempre es cuantificable [13].

La productividad se define como lo que las personas pueden producir con el menor esfuerzo [128].

Sutermeister simplemente define la productividad como la producción por hora del empleado, calidad considerada [152].

Dorgan define la productividad como el mayor rendimiento funcional y organizativo, incluida la calidad [35].

Un aumento en la productividad se expresa como una reducción directamente cuantificable del absentismo. Sin embargo, la mejora en la productividad también puede ser el resultado de un aumento en la cantidad y la calidad de la producción durante el período en que los empleados están trabajando activamente [126].

Otros modos de evaluar la productividad han incluido mediciones de tareas cognitivas estandarizadas, tales como memoria, atención y tareas matemáticas. Sin embargo, esto no es productividad en el sentido del trabajo real, pero se aproxima al tipo de tareas que la mayoría de personas suelen realizar [167].

Frecuentemente, las mediciones indirectas de productividad incluyen el **absentismo**, **“presentismo”** y **lentitud**. La idea detrás de estas mediciones es que las personas no pueden trabajar eficazmente cuando están enfermos o tienen una escasa motivación.

Mientras que estas son mediciones útiles, resulta difícil identificar todas las potenciales formas en las que los productos y servicios entregados se pueden ver influenciados por estas mediciones. Por ejemplo, unos altos niveles de absentismo laboral pueden ser debidos a circunstancias externas o a una mala gestión de la organización, así como por el espacio de trabajo. Los mejores estudios de investigación hasta el momento tienen en cuenta estos factores [185].

Hay muchos factores, entre otros, como el nivel de educación, aptitudes, edad, género, estados emocionales y sesgo de respuesta que deben considerarse al investigar la relación entre la arquitectura interior y la productividad del ser humano [23], [88], [116].

En consecuencia, la selección precisa de los sujetos experimentales fue parte de la herramienta presentada en esta investigación.

Para el propósito de esta investigación, se ha tenido en cuenta la precisión y la velocidad como los dos aspectos distintos de la productividad del ser humano. La exactitud es una medida de la calidad.

Las medidas de precisión incluyen el número correcto, el porcentaje correcto y la probabilidad de detecciones correctas [51]. Los estudios de laboratorio generalmente evalúan la productividad laboral al hacer que los sujetos realicen tareas cognitivas que simulan aspectos del trabajo real y una evaluación subsiguiente de la velocidad (tiempo de respuesta) y la precisión (errores porcentuales).

Por ejemplo, número de teclas pulsadas por unidad de tiempo, número de unidades de suma o multiplicación completadas por unidad de tiempo, etcétera [11], [88], [89], [171], [172], [174], [178], [182].

2.3 Concepto II. Biofilia.

Las Naciones Unidas pronostican que, en el año 2030, el 60% de la población mundial vivirá en entornos urbanos [1]. Por lo tanto, es imperativo que consideremos cómo se puede mantener la conexión entre las personas que residen en las ciudades y la naturaleza, y cuáles son los parámetros de mayor impacto en el bienestar, la salud y la productividad de las personas. Los autores más relevantes han declarado que la respuesta a este desafío es el diseño biofílico [18], [162].

El biólogo y entomólogo estadounidense, Edward O. Wilson, fue el primero en formular la hipótesis de que el contacto con la naturaleza es esencial para el desarrollo psicológico de las personas. Su teoría establece que durante millones de años nuestra especie estuvo relacionada con su entorno salvaje, creó una especie de dependencia, una necesidad emocional abrumadora de estar en contacto con otros seres vivos. Esta necesidad inherente fue llamada Biofilia [176], [177].

Entre 1993 y 1995, los científicos Roger S. Ulrich y Stephen Kellert especificaron el enfoque final del término Biofilia definiéndolo como "la afinidad humana innata por la naturaleza" [81], [162] y establecieron la base de la aplicación de esta sensibilidad al diseño y la arquitectura [82].

La incorporación del concepto de Biofilia significa acercar la naturaleza al entorno urbano, evocando la doble esencia del ser humano: social y natural [18].

El desafío del diseño biofílico es abordar las deficiencias de la arquitectura contemporánea en edificios, paisajes e interiores, iniciando un nuevo marco para la experiencia beneficiosa de la naturaleza en el entorno urbano [83].

Un informe sobre el espacio humano en Europa, Oriente Medio y África, publicado en 2014 [180], examinó específicamente el impacto del diseño biofílico en esa área geográfica y sirvió de base para un proyecto de investigación global. Esta investigación cuantifica los beneficios del diseño biofílico en los espacios de trabajo que recopilan datos de dieciséis países de todo el mundo, en el entorno urbano actual, las personas están cada vez más aisladas de la experiencia beneficiosa de los sistemas y procesos naturales. Al imitar estos entornos naturales en los lugares de trabajo, se les proporciona experiencias emocionales positivas [18].

La investigación realizada entre los trabajadores para descubrir qué elementos son los más valorados en su entorno de trabajo, muestra que la luz natural es el elemento más buscado dentro del lugar de trabajo [1], [2], [80].

De manera similar, las plantas de interior y los colores vivos se clasifican entre los cinco primeros [1], [2], [80].

En el trabajo, cuando enfocamos nuestra atención en una tarea exigente, los factores en nuestro entorno que nos interrumpen pueden llevar a la fatiga mental [58].

Sin embargo, los lugares de trabajo que incorporan la naturaleza proporcionan ajustes más tranquilos que facilitan la atención y pueden restaurar nuestra capacidad mental. Esto se conoce como la Teoría de la Restauración de la Atención, que postula que ver y experimentar la naturaleza implica una parte diferente del cerebro que se utiliza en el enfoque de alta atención [44], [166].

Existe una interacción continua y dinámica entre las personas y su entorno que produce una tensión fisiológica y psicológica en la persona, que en consecuencia conduce a cambios en la salud, el bienestar y el rendimiento [23], [89], [116].

En esta investigación, se destaca la aparición de certificaciones que garantizan que un lugar de trabajo responde a los criterios de Biofilia y, por lo tanto, contribuye a la productividad, el bienestar y la salud de las personas, como las certificaciones Fitwell [45] o WELL [31], [71].

2.4 Concepto III. Experimento Piloto.

El término experimento piloto se usa como una versión a pequeña escala realizada en preparación para el estudio principal [120].

Una de las ventajas de realizar un experimento piloto es que puede proporcionar una advertencia avanzada sobre dónde puede fallar el proyecto principal de investigación, dónde no se pueden seguir los protocolos de investigación o si los métodos propuestos son inapropiados o demasiado complicados [163].

Los experimentos piloto son un elemento crucial del buen diseño del estudio. La realización de un experimento piloto no garantiza el éxito en el estudio principal, pero sí aumenta la probabilidad [163].

El experimento piloto cumple una serie de funciones importantes y puede proporcionar información valiosa para otros investigadores [163].

3. ESPACIOS DE TRABAJO

3.1 Recorrido Histórico.

ROMA.

Las oficinas han existido de alguna manera o forma a lo largo de la historia como un medio de que una persona, o grupo de personas, pueda llevar a cabo la administración de negocios. Se basa en el latín romano *officium*, un término que significa vagamente "oficina", o personal humano o posición formal. En la antigua Roma, no era tanto un lugar específico ni un edificio, sino la gente dentro de él [135].

Por ejemplo, de ahí nacen frases como "La Oficina del Primer Ministro". Los romanos tenían una habilidad única para usar solo técnicas de construcción probadas en el tiempo que inspiraban la organización y el orden para afrontar los procesos burocráticos centrales, como se ejemplifica en el Panteón todopoderoso y arcaico en el moderno distrito comercial de Roma [135].

Figura 1. Panteón en Roma, la primera oficina que se reconoce en la Historia.

LAS PRIMERAS OFICINAS MODERNAS.

Llama la atención que las organizaciones de gran escala y multifuncionales relativas al gobierno burocrático romano no existieron en el mismo tamaño y complejidad hasta el siglo XVIII [125].

Organizaciones como la *Royal Navy* y se establecieron para promover los intereses de Gran Bretaña en el exterior y, para administrar sus variadas tareas y organización, era necesario construir una base central de operaciones [48], [125].

East India House se construyó en 1729 en *Leadenhall Street* como el cuartel general desde el cual East India Company administraba sus intereses indios y requería que miles de empleados procesaran los documentos necesarios [125].

Al igual que los políticos romanos, *The East India Company* comprendió la necesidad de una administración centralizada, y la eficiencia que esto trajo a lo que esencialmente era un proceso de hacer y distribuir grandes cantidades de dinero [48], [125].

De esta manera, muchas organizaciones no políticas siguieron su ejemplo, como la *Oficina del cuatro por ciento* del arquitecto John Soane en el Banco de Inglaterra, erigida en 1793 [125].

Figura 2. East India House, primera oficina moderna.

Figura 3. El “Antiguo Almirantazgo” (Edificio Ripley), construido en 1726, fue el primer edificio de oficinas construido para este propósito; mientras que muchas oficinas más pequeñas para la Royal Navy se consolidaron en Somerset House como el primer bloque de oficinas especialmente diseñado para esa función, a lo largo de la década de 1770.

Figura 4. La *Oficina del cuatro por ciento*, obra del arquitecto John Soane, 1793.

EL PRIMER RASCACIELOS.

El primer "rascacielos" en Europa, por definición, se sostiene que es el *Oriel Chambers* en Liverpool, Reino Unido [42]. Completado en 1864 por el arquitecto Peter Ellis, el "rascacielos" solo tiene cinco pisos de altura, y es el primer edificio en la historia en contar con un muro cortina de vidrio con marco de metal.

Si bien no es un "rascacielos" según los estándares actuales, el famoso logro arquitectónico de Ellis empleó una estructura interna de hierro, eliminando la necesidad de muros para apoyarlo [42], [48].

Esto permitió que el icónico muro cortina de vidrio inundara todos los pisos del edificio con luz natural durante el día y que más personas usaran un área de superficie más amplia del espacio de la oficina con una necesidad mínima de luz artificial. *Oriel Chambers* ha sido utilizado casi exclusivamente por profesionales legales desde 1965 [42].

Figura 5. El primer "rascacielos" de Europa. *Oriel Chambers*, 1864.

EL AUGE DE LOS RASCACIELOS DE OFICINAS.

Si bien el edificio *Oriel Chambers* fue inicialmente muy controvertido, obtuvo críticas negativas de los medios contemporáneos. Asimismo, influyó en muchos contemporáneos, en particular, John Welborn Root, quien pasó de ser un adolescente que vivía en Liverpool a convertirse en un importante arquitecto de la Escuela de Arquitectura de Chicago [48].

Es importante destacar que esto sugiere que hubo un traspaso considerable de las ideas de Peter Ellis a Estados Unidos, influyendo en muchas de las construcciones de rascacielos pioneras de Burnham y Root en la década de 1880 [42].

Oriel Chambers ha sido descrito por los estudiosos de historia de la arquitectura como "notable", incluso "increíble" en su tiempo. Se puede argumentar que es la influencia de la destreza arquitectónica de Ellis a lo largo de América lo que dio origen a los emblemáticos rascacielos de Chicago y Nueva York en el siglo XX, comenzando con el primer ejemplo de muros de cortina de cristal de los EE. UU: el edificio *Boley* de Misuri, finalizado en 1909 [42], [48].

La icónica obra maestra arquitectónica de Ellis llevó al establecimiento de edificios de oficinas de rascacielos en todo el mundo, permitiendo superficies de oficinas más amplias y con iluminación natural [42].

LAS OFICINAS MODERNAS.

Diversos factores dieron lugar a las oficinas modernas de principios del siglo XX. Algunos de estos factores son [19], [48], [123]:

- El vínculo entre mundo financiero y productividad laboral.
- La invención de la iluminación eléctrica, que permite a los empleados trabajar sin la costosa iluminación de gas.
- La aparición de máquinas de escribir y máquinas de cálculo, que permiten el procesamiento de grandes cantidades de información.
- Dispositivos de comunicaciones como el telégrafo y el teléfono, que permiten que los edificios de oficinas se puedan ubicar lejos de fábricas, hogares e incluso países en los que operan, pero sin perder el control sobre estos.

El alto precio del suelo, junto con los inventos del ascensor y de la construcción de estructuras de acero, permiten edificios de más de diez pisos. Esto dio lugar a los rascacielos del siglo XX en Chicago y Nueva York, incluyendo el icónico edificio *Wainwright* en St. Louis, Missouri [48].

Esto condujo en última instancia a la rápida evolución del diseño de oficinas a principios del siglo XX. Los mayores grupos de empleados podrían trasladarse a oficinas amplias y abiertas, trabajando con luz natural o bajo iluminación eléctrica [48], [123].

Se proporciona aislamiento acústico y particiones para aislar a los empleados del ruido, calor o contaminación excesivos. La llegada de los rascacielos permitió a las empresas reducir en diez veces la superficie necesaria para alojar a sus empleados [123].

La Revolución Industrial había modernizado completamente el trabajo manual y la producción. El diseño de oficinas ahora comenzaría a modernizar la mano de obra profesional de una manera similar [48].

1900: OFICINAS TAYLORIANAS.

Frank Lloyd Wright tiene el mérito de haber desarrollado la primera oficina *tayloriana* comercialmente viable para una empresa de pedidos por correo en 1904 [48].

El edificio *Larkin* alojaba a 1800 trabajadores, procesando 5000 pedidos por día en un espacio central abierto en el corazón del edificio [48].

Para limitar la acumulación de contaminación de la línea ferroviaria cercana, se instaló un sistema de aire acondicionado innovador, aunque primitivo, y el edificio estaba herméticamente sellado [48].

El edificio tenía inscripciones de mensajes saludables, sugiriendo que la compañía se parecía a una familia, o a una máquina bien engrasada, dedicada al "sacramento del trabajo"[48].

La naturaleza de la cadena de montaje del procesamiento de pedidos por correo, junto con la casi ausencia de vistas al exterior que los empleados recibían a lo largo del día, reforzó esta visión [48].

La atención de Wright a los detalles se extendió al diseño del primer "sistema" de muebles, escritorios, gabinetes y divisores incorporados para mantener a los empleados enfocados y las superficies de las mesas ordenadas [48].

Esta oficina era en gran parte producto de la revolución industrial de finales del siglo XIX. Desarrollado por el lado de la "Gestión Científica", Frederick Winslow Taylor, la oficina *Tayloriana*, por diseño, pretendía mejorar enormemente la eficiencia de las empresas que no dependían necesariamente de la fabricación o el trabajo manual [48].

Taylor, un defensor del “Movimiento de Eficiencia”, esperaba imitar la “línea de montaje” de la fábrica de la época al delegar tareas manuales simples y repetitivas a empleados de empresas legales y de contabilidad, compañías de seguros y agencias gubernamentales para crear un flujo de trabajo constante [48].

Las otras ganancias obtenidas del plan de la oficina *Tayloriana* incluyeron la instalación de más escritorios, y por lo tanto más trabajadores, en una habitación, así como permitir que gerentes y supervisores escudriñen a los trabajadores más fácilmente. Naturalmente, la alta dirección todavía tenía sus propias oficinas [48].

Figura 6. El edificio Larkin alojaba a 1800 trabajadores y procesaba 5000 pedidos diarios.

1910-1930: LA OFICINA DEMOCRÁTICA DE ANTES DE LA GUERRA MUNDIAL.

Haciéndose eco de los rascacielos de Chicago y Nueva York, muchos países europeos vieron un aumento en los "rascacielos en miniatura", así como en "oficinas *taylorianas* en miniatura" a lo largo de los primeros treinta años del siglo XX [48].

Arquitectos como Mies van der Rohe diseñaron edificios de oficinas de hormigón con "ventanas continuas", a una altura por encima de la cabeza, para dejar entrar la luz, pero no permitir que los empleados vean el exterior desde sus escritorios [48].

Estos diseños carecían de financiación en su momento, debido a la depresión inducida por el colapso de Wall Street en 1929 y las economías prevaletentes durante la guerra, pero hay muchos ejemplos de ideas sin construir [48].

El proyecto de muro cortina de cristal de Le Corbusier para las oficinas gubernamentales de Brasil de 1936 proporcionó ese ejemplo; o "la transacción literal y organizativa de un estado democrático moderno" [48].

Estos diseños aún utilizaban los principios taylorianos ahora arraigados, pero debido al mayor énfasis puesto en las fuentes de luz natural, el plan abierto tayloriano tuvo que ser incorporado en una escala menor. Un ejemplo construido es el edificio Friedrichstrasse del arquitecto van der Rohe [48].

Figura 7. El rascacielos *Friedrichstrass*. Berlín, 1921.

Figura 8. Planta del rascacielos *Friedrichstrass*.

1930: LA OFICINA DINÁMICA.

La década de 1930 dio lugar a las mejores obras desde el punto de vista estético, así como a los espacios diseñados para la eficiencia y la velocidad, en lugar de la organización y la manufactura. Los "ruidosos años 20" habían llegado a su fin con el *crash* en 1929, y las principales corporaciones se interesaban principalmente por dos aspectos: unas oficinas que expresaran su imagen corporativa; y hacer el trabajo con menos coste y en menos tiempo [48], [174].

Sin embargo, esto no supuso un cambio radical respecto a los principios *taylorianos*, basados en una jerarquía clara y rígida que dictaba las órdenes de trabajo a través de una "planta de trabajadores" separada.

El cambio que introdujo la Oficina Dinámica se desarrolló en conjunto con edificios arquitectónicos modernos: se logró un espacio más moderno, rico y cálido para los trabajadores, utilizando materiales radiantes y aerodinámicos para compensar la falta de interacción con el mundo exterior [48], [174].

Uno de los principales ejemplos de este tipo de oficina fue el edificio *Johnson Wax* de Frank Lloyd Wright, construido en Racine, Wisconsin, que se finalizó en 1939. Los 250 trabajadores se encontraban en una única gran sala aislada. Humo y ruido, así como gerentes, ejecutivos de la empresa y maquinaria ruidosa estaban en salas separadas [48], [174].

Las principales diferencias entre el nuevo *Johnson Wax Building* y sus antecesores *taylorianos* fueron la presencia de luces brillantes, espacios clínicos, blancos, cálidos y techos de corcho para "absorber el sonido que se eleva desde el pavimento de goma y mezclarlo en un zumbido apacible" [48], [174].

En todo caso, se podría argumentar que la Oficina Dinámica fue una obra de diseño *tayloriano*, pero mejorada y actualizada por la extravagancia de los años 20 y la invención de nuevos materiales de primera calidad [48], [174].

En estas áreas, el edificio *Johnson* se considera históricamente como un éxito, ya que los trabajadores pasaron más tiempo, tanto de ocio como de trabajo, dentro del edificio como resultado directo de su diseño y función [48], [174].

Figura 9. *Johnson Wax Building*, obra del arquitecto Frank Lloyd Wright. EEUU, 1939.

1950: OFICINAS DE PLANTA ABIERTA.

El comienzo de la década de 1950 trajo consigo nuevos avances en la construcción con materiales modernos como el acero y el vidrio. La arquitectura inteligente y clínica del movimiento moderno internacional se adoptó como la nueva imagen del negocio corporativo [19], [48].

Con el uso generalizado del aire acondicionado y la iluminación fluorescente, estos nuevos edificios de gran altura tenían muy poca necesidad de luz natural o ventilación a través de la apertura de ventanas [19], [48].

Con estos desarrollos tecnológicos, en la década de 1950, la oficina corporativa se volvió completamente autónoma del mundo exterior, además de permitir plantas más amplias y abiertas donde los trabajadores podían ubicarse prácticamente en cualquier lugar [19], [48], [168].

Estos desarrollos arquitectónicos llevaron a ejemplos tan icónicos como *The Lever House*. Terminada en 1952 en la ciudad de Nueva York, la sede de la compañía británica de jabón, *Lever Brothers*, fue el primer rascacielos de Nueva York en tomar prestado el "muro cortina de vidrio" de *Oriel Chambers* de Peter Ellis [19], [48].

La imagen moderna de *Lever House* de la eficiencia y la estandarización comenzó una tendencia en los años 50 y 60 que vio surgir una serie de "cajas de cristal" a través del horizonte de Nueva York, expresando el dominio comercial y cultural de la ciudad [19], [48].

Estos rascacielos permitieron que incluso más luz natural inundara las amplias superficies de las oficinas, al igual que el muro cortina de cristal de Le Corbusier tenía la intención de hacerlo 20 años antes [19], [48], [168].

Skidmore, Owings & Merrill, la firma detrás de *Lever House*, diseñó *Chase Manhattan Bank*, que terminó en 1961. Los arquitectos, Gordon Bunshaft y Natalie de Blois, siguieron la naturaleza jerárquica del negocio corporativo, colocando a los empleados administrativos en planta abierta, gerentes en oficinas individuales y ejecutivos en el lujoso piso sesenta [19], [48].

Hasta mediados del siglo XX, las oficinas de este estilo abierto fueron reinterpretadas con objetivos de mayor rentabilidad económica [19], [48], [168].

1950: BÜROLANDSCHAFT.

Bürolandschaft se traduce literalmente como "oficina paisaje", y puede verse como la primera reinención del espacio de oficinas más importante desde que el taylorismo apareció hace casi 50 años antes [19], [48].

Se trata de una nueva forma de oficina abierta, en la que Eberhard y Wolfgang Schnelle, en Hamburgo, buscaron "romper las estructuras rígidas e ineficaces de las grandes organizaciones burocráticas de planta abierta, y diseñar la organización espacial de la oficina de acuerdo con las necesidades de trabajadores" [19], [48].

A diferencia de estricta y reglamentada organización de los espacios de oficina *tayloristas*, tanto de planta abierta como dinámicos, la oficina paisaje consistía en superficies libres y abiertas de muebles repartidos en espacios grandes, de forma holgada y desestructurada, con diferentes ambientes [19], [48].

Estos entornos variados se dividían de manera menos rígida, usando creativamente las particiones, y siendo la naturaleza de ellas a menudo dictada por el tipo y la función de los trabajadores que las habitaban [19], [48].

Por ejemplo, los trabajadores en campos creativos (como la publicidad o los medios de comunicación) podrían agruparse de manera flexible donde podrían interactuar con mayor frecuencia, mientras que el personal de gestión administrativa se ubicaba en áreas más reglamentadas y subdivididas [19].

No fue una sorpresa que Bürolandschaft emanara del norte de Europa casi inmediatamente después de la Segunda Guerra Mundial [19].

Paralelamente a la Guerra Fría: una gran guerra “silenciosa”, más de ideologías que de ejércitos, la “oficina paisaje” engendró un enfoque de gestión igualitaria. Basado en los principios socio-demócratas y progresistas, el sistema reconoció y permitió la gran diversidad de diferentes trabajos de oficina, y al hacerlo, alentó al personal de múltiples niveles a sentarse y trabajar juntos, en un esfuerzo por mejorar la colaboración y la comunicación en el ambiente de la oficina [19].

Aunque Bürolandschaft disfrutó de un breve período de popularidad en Europa, además de establecerse dentro de algunas oficinas británicas a finales de la década de 1960, la naturaleza pura de su diseño abierto, disperso y algo al azar no se prestó bien a la adopción mundial [19], [48].

“Action Furniture” fue desarrollado para adaptar el escritorio a este nuevo entorno de oficina, mitigar el ruido y abordar los problemas de privacidad, pero esto finalmente terminó por socavar el concepto detrás de Bürolandschaft [19].

1960: HERMAN MILLER Y LA OFICINA DE ACCIÓN.

De los principios socio-demócratas de Bürolandschaft surgió la Oficina de Acción de Herman Miller, definida por una serie de escritorios, espacios de trabajo y otros muebles modulares diseñados para permitir la libertad de movimiento y flexibilidad para trabajar en una posición adecuada para el trabajo que se está realizando [12], [19], [48].

Action Office fue desarrollada y comercializada bajo la supervisión de George Nelson y Robert Propst, quienes fueron de los primeros diseñadores en argumentar que el trabajo de oficina era trabajo mental y que el esfuerzo mental estaba vinculado a un entorno de trabajo adecuado [12], [86].

Action Office puede verse como el primer ejemplo destacado de un sistema de espacio de oficina basado en los principios modernos europeos de posguerra responsables de iconos de la arquitectura como el Edificio *Seagram* de Mies van der Rohe o el Museo *Whitney* de Arte Americano de Marcel Breuer [12], [86].

La afluencia de mujeres en el lugar de trabajo después de la Segunda Guerra Mundial también llevó a cambiar la dinámica de la oficina. En 1968, *The Observer* publicó un artículo titulado: “¿Permitiría que su hija trabajara en una oficina de planta abierta?” [12].

Las buenas habilidades de secretaría fueron muy importantes en la década de 1960, lo que permitió a las mejores secretarías exigir la llamada “**junta de cortesía**” (una sección de madera contrachapada que cubría todo el frente de un escritorio y las piernas de la secretaria) [12].

Permitir que las mujeres usaran pantalones en la oficina, como una solución mucho más simple, era relativamente poco conocido en las oficinas británicas hasta mediados de los años setenta [12], [86].

Action Office se diseñó inicialmente con oficinas pequeñas en mente, donde el personal trabajaba en la misma habitación, con los mismos muebles. Esto trajo sus propios problemas, debido a que los muebles estaban hechos a medida y fabricados con materiales de alta calidad, lo cual resultaba excesivamente costoso para los gerentes de las empresas [12], [19], [48].

Lo anteriormente descrito, combinado con la necesidad de reemplazar los muebles con las necesidades cambiantes de la oficina, lo hizo financieramente y prácticamente inviable para oficinas corporativas más grandes [12], [86].

LA OFICINA DE ACCIÓN, VERSIÓN II.

Después de una lenta aceptación y escasas ventas de Action Office I, Propst y Nelson regresaron a la mesa de dibujo, comenzando a trabajar en la siguiente versión de Action Office. Lo que resultó fue el concepto de una oficina tan flexible como la Action Office I, en el sentido de que podía modificarse para adaptarse a las necesidades cambiantes del empleado, sin la necesidad de comprar muebles nuevos y costosos [12], [19].

El nuevo sistema fue diseñado para permitir al personal un grado de privacidad, así como la opción de personalizar su entorno de trabajo sin afectar los entornos de sus compañeros [12], [19].

El descubrimiento de Propst del vínculo entre productividad de los empleados y su propio espacio de trabajo personalizado, llevó a un concepto llamado "back-up", que consistía en una división vertical de tres lados, que define el territorio y ofrece privacidad sin separar completamente a los empleados del entorno [12], [19].

De esta manera, Action Office II, a pesar de su concepto original basado en la flexibilidad, iniciaría el proceso para establecer las "granjas de cubículos" de la década de los ochenta [12], [19].

Figura 10. Ejemplo de Action Office versión II en la década de 1960.

A finales de la década de 1950, la supremacía de la ciudad moderna y funcional había sido criticada, y algunos diseñadores buscaron patrones más tradicionales [12], [19].

El arquitecto holandés Herman Herzberger desarrolló un tipo de arquitectura que dio lugar a nuevas estructuras de oficinas innovadoras [12], [19].

El proyecto de 1974 de Herzberger, el edificio de seguros *Centraal Beheer* en Apeldoorn, Holanda, fue diseñado para permitir que el personal “se sienta parte de una comunidad de trabajo sin perderse entre la multitud” [12], [19].

Era casi un edificio que alberga varios edificios más pequeños e individuales, una forma estructural diseñada para “diferenciar entre un continente con un ciclo de vida largo y un contenido con ciclos de vida más cortos” [12].

De esta manera, el *Centraal Beheer* era un conglomerado espacial de hormigón y ladrillo con dibujos en forma de cuadrícula, casi laberíntico en su diseño. Las plataformas separadas por pozos de luz permitían que la luz se filtrara hacia el centro de la planta [12].

Tomando como guía el estudio de Robert Propst, se alentó a los empleados a personalizar y decorar su espacio. Como resultado, muchos trabajadores trajeron las comodidades, muebles y miembros de su familia del hogar al trabajo [12], [19].

Sin embargo, aunque la estructura funcionó correctamente a menor escala, su arquitectura laberíntica no se prestó para ser escalable a espacios públicos más grandes [12], [19].

Además de esto, el amplio e intrincado diseño del edificio *Centraal Beheer* hacía que los empleados se perdieran en su interior, dando lugar a situaciones grotescas [12].

Figura 11. Planta del Edificio *Centraal Beheer*. Holanda, 1958.

Al igual que en el edificio de Johnson Wax de la década de 1930, el diseño de la Oficina estructuralista demuestra el aumento del número de trabajadores de oficina en Europa [12], [19].

La decisión de la compañía de ubicar el bienestar y la satisfacción de sus empleados por encima de la eficiencia y la economía hace que la arquitectura del espacio de oficinas de Herzberger se aparte de los principios arcaicos e industriales tayloristas y de los elementos de la Action Office que inevitablemente se convertirían en las "granjas de cubículos" de los años ochenta [12].

1980: LA GRANJA DE CUBÍCULOS.

La Granja de Cubículos surge a partir de una evolución malinterpretada de la Action Office de los años 60. Este modelo antepone la rentabilidad del espacio al bienestar de los empleados [10], [19], [48].

Robert Propst, que había imaginado la Action Office como un medio para liberar a los empleados de la naturaleza aburrida y mecánica de la planta abierta de Taylor, **afirmó algo tan rotundo como que** “no todas las organizaciones son inteligentes y progresistas [19], [48].

Los lotes están a cargo de personas groseras que pueden tomar el mismo tipo de equipo que otros y crear infiernos. Hacen pequeños cubitos y meten a la gente en ellos. Lugares estériles, **ratoneras**” [12], [84].

Esta mentalidad abiertamente económica, combinada con la naturaleza acelerada de la década, dio como resultado un rápido aumento del personal de mando intermedio, demasiado importante para ocupar un puesto de trabajo en una planta de oficina taylorista, pero demasiado joven para un despacho propio [72].

Estos trabajadores necesitaban ser acomodados en su propio espacio, pero de la manera más flexible y económica posible como sea posible. De esta manera, nace “el mar” de cubículos [86].

Douglas Ball, diseñador de Haworth, una de las compañías de muebles rivales de Herman Miller, desarrolló uno de los muchos diseños impostados de la Action Office II. Inicialmente emocionado, después de ver el **resultado de la implantación, afirmó con tristeza:** “fui a ver la primera instalación del sistema, un gran proyecto gubernamental [19], [48].

Los paneles tenían una altura de 1,70 metros, por lo que, a menos que tengas una estatura de más de 1,90 metros, no podrías mirar por encima [86].

"Fue horrible, una de las peores instalaciones que había visto", dijo Ball. "Pensamos que era extremadamente flexible en planta, pero nunca habíamos considerado el alzado vertical". Para entonces, ya era demasiado tarde para remediar el problema [86].

De hecho, para dejar entrar luz y aire, agregó, "tendrías que ir con una motosierra y cortar las partes superiores de los paneles". Ball, como muchos de sus contemporáneos, había atrapado a empleados en una telaraña gigante, envueltos en paredes que Propst quiso eliminar veinte años antes [86].

La Granja de Cubículos es una lección de historia que demuestra que cualquier buena idea puede ser corrompida por cualquiera con más interés en la economía o la eficiencia que en las personas. Mostró que las grandes empresas corporativas tenían poco interés en crear entornos excelentes para el personal [86].

En cambio, la Action Office II y sus muchas copias se usaron para meter al máximo número de personas posible en un espacio mínimo, lo más barato y lo más rápido posible [19], [48].

1990: LA OFICINA VIRTUAL.

Uno de los grandes desarrollos de la década de 1990, si no el más grande, fue la creciente facilidad de acceso a Internet, con efectos innovadores en el trabajo de oficina que no podían ser ignorados [86].

Casi cien años después, Internet trajo consigo el desarrollo de un fenómeno de oficina que se vio por primera vez a principios del siglo XX: la nueva tecnología generalizada, computadoras portátiles y teléfonos móviles podrían alejar a los empleados de las oficinas [86].

La recesión de principios de la década de 1990, combinada con la creciente competencia en mercados cada vez más globalizados, afectó a muchas empresas, cuyos directores ejecutivos y directores gerentes no podían ignorar los ahorros de costes que suponía el teletrabajo y la externalización facilitados por las telecomunicaciones avanzadas [83].

Los crecientes precios y rentas del suelo en las áreas edificadas fueron en aumento, las empresas multinacionales se mudaron fuera de los centros de las ciudades, a los parques industriales y a zonas infrautilizadas y mal comunicadas. Esto originó el rápido desarrollo de parques industriales, o "no lugares" [86].

1990: AGILE WORKING Y LA BURBUJA DEL DOT COM.

La intensa reorganización del diseño de oficinas en la década de 1990 también tuvo lugar en una gran multitud de las llamadas *Dot Com* o "Compañías de Internet" [19].

Los grandes avances en el desarrollo de la tecnología de telecomunicaciones, llevaron a los primeros avances en el trabajo a distancia y el trabajo flexible [19].

Una gran cantidad de empresas *Dot Com* a finales de la década de los años 90 acogía oficinas más pequeñas, más extravagantes y más coloridas que se alineaban con su nueva imagen fresca y progresista [19].

Desde fracasos minoristas como *boo.com* y *pets.com*, hasta intentos de medios digitales como *ritmoteca* y *pseudo.com*; el final del siglo XX vio aparecer docenas de compañías nuevas, supuestamente innovadoras, que abren sus coloridas puertas y las cierran con la misma rapidez [19].

Las extravagantes e informales oficinas producidas por la burbuja *Dot Com* de finales de los años 90 aún conservaban elementos de la oficina de planta abierta, pero añadiendo esquemas de colores fuertes y diseño novedoso [19].

Esto inspiró los diseños de oficina de planta abierta de hoy: planes "des-territorializados" donde los límites entre las personas y los espacios, así como aquellos entre el trabajo y el juego, están borrosos [19].

En contraste con los laberintos de cubículos grises de la década anterior, el auge de la tecnología de las telecomunicaciones a finales del siglo XX fue el primer gran ejemplo de cómo el avance tecnológico podría revolucionar los esquemas de trabajo [19].

La llegada de la tecnología ha llevado a que los empleados tengan menos necesidad de estar atados a sus puestos de trabajo, lo que se traduce en la innovadora configuración de trabajo ágil de algunas de las compañías *Dot Com* que sobrevivieron después de los años 2000, como Google [19].

El gigante de las búsquedas siempre ha inspirado una cultura de trabajo de colaboración e intercambio de opiniones e ideas, independientemente del rol del empleado en la empresa; y la oficina de Google en California, reflejaba un estilo de trabajo que fue completamente revolucionario a comienzos del siglo XXI [19].

2000: LA OFICINA INFORMAL.

La oficina informal surge como tendencia desde mediados de la década de 1980, iniciada por empresas vinculadas a industrial relacionadas con la creatividad [19].

Desde grandes empresas de Silicon Valley como Apple, Intel, Microsoft y Tesla, y a través de los gigantes del *Dot Com* como Yahoo, Google y eBay, pasando por empresas más pequeñas de Marketing Digital: todas estas empresas han adoptado estilos de oficina más informales, diseñados para fomentar espacios de trabajo altamente personalizados que se adaptan a largas horas de programación, análisis de datos, creación de enlaces o diseño de gráficos [19].

El "código de vestimenta", si hubiera uno, de tal oficina se volvió mucho más relajado que los "trajes y corbatas" convencionales del siglo anterior, y los diseños debían reflejar esto [19].

PRESENTE Y FUTURO: ACTIVITY-BASED WORKING, AGILE, FLEXIBILIDAD, BIENESTAR, SOSTENIBILIDAD.

Una de las principales críticas a los diseños de oficinas de planta abierta, ya sean tayloristas o informales, es la idea de “receta única” para que todos los empleados puedan trabajar de manera diferente, en proyectos completamente diferentes, pero en el mismo espacio [20], [75].

Si bien esto fomenta la colaboración y la apertura, al hacerlo, también crea distracciones y estrés innecesarios para aquellos que necesitan privacidad, equipos especiales o simplemente un espacio tranquilo donde concentrarse [20], [75].

La solución a esto no son las oficinas sectorizadas o los cubículos grises de antaño. Los espacios de trabajo dinámicos y basados en actividades para adaptarse a diferentes estilos de trabajo son clave para alejarse de los inconvenientes de la oficina de planta abierta [20], [75].

Los espacios contemporáneos que permanecen abiertos, pero separados, permiten la colaboración, la inspiración, la movilidad y la finalización de proyectos, sin preocupación de aglomeraciones o interrupciones entre distintos estilos de trabajo [20], [75].

A los empleados se les presenta una gama de espacios de trabajo logísticamente diferentes para elegir los que se adapten mejor a sus necesidades individuales en ese momento, incluido su propia mesa de trabajo, salas de reuniones abiertas con pizarras, suites informáticas o espacios informales con café y comida [20], [75].

Los entornos de trabajo ágiles apuntan a ser el futuro. Permitir que el personal trabaje de manera efectiva en diferentes entornos dentro del mismo espacio es clave tanto para la productividad como para el bienestar en el lugar de trabajo [20], [75].

Sin embargo, actualmente las oficinas han comenzado a incorporar espacios para acomodar una gama de diferentes estilos de trabajo, todo dentro del mismo espacio. Reuniones anuales, revisiones individuales, reuniones de equipo o simplemente espacios colaborativos, deben lograrse dentro de un espacio limitado [20], [75].

A esto hay que sumar el hecho de cada vez una mayor tasa de la población activa trabaja desde su hogar, haciendo que la necesidad de espacios adaptables y flexibles se vuelva aún más evidente [20], [75].

Las salas de reuniones fijas y formales no se utilizan constantemente, y pueden ser una carga para las finanzas, así como para el espacio de trabajo [20], [75].

Este cambio emergente hacia espacios de trabajo adaptables a las prácticas de trabajo a medida no solo ahorra espacio y dinero, sino que también permite que los empleados tengan lo mejor de ambos mundos: colaboración y comunicación, y paz, tranquilidad y privacidad cuando lo necesitan [20], [75].

Los espacios de oficinas contemporáneos deben permitir un número diferente de personas, conteniendo desde cabinas telefónicas unipersonales, hasta agrupar salas para grupos pequeños, salas ruidosas para trabajo informal, creativo, colaborativo y salas tranquilas para actividades de carácter más introspectivo [20], [75].

Este deseo de un espacio de trabajo colaborativo y, sin embargo, adaptable ha facilitado la incorporación de "terceros espacios" o "espacios intermedios": áreas de trabajo sin un propósito rígido, pero con la capacidad de adaptarse a múltiples estilos de trabajo en diferentes tipos de proyectos [20], [75].

A lo largo de los últimos dos siglos, se han promulgado varias leyes en distintos países sobre el lugar de trabajo, para proteger y promover el bienestar de los empleados [20], [75].

Ya sea en fábricas con mano de obra, en líneas de montaje o en puestos de oficina administrativos, se ha hecho evidente a lo largo de la historia de la oficina que las empresas necesitan cuidar el bienestar, la comodidad, la salud y la felicidad de los trabajadores [20], [75].

Estas iniciativas de bienestar no solo están en línea con los precedentes legales, sino que muchos empleadores han encontrado, como era de esperar, distintas correlaciones positivas entre el bienestar de los empleados y su rendimiento laboral [20], [75].

Las iniciativas de bienestar en el lugar de trabajo no solo ahorran dinero al aumentar la productividad y reducir el absentismo, sino que también hacen que el personal se sienta valorado y produce un equipo mucho más efectivo, cohesivo y motivado de lo que existiría de otra manera [20], [75].

Debido a esto, muchas empresas con visión de futuro han tomado en cuenta los cambios necesarios para mejorar el bienestar en el lugar de trabajo al diseñar y equipar un nuevo espacio de oficina [20], [75].

En un mundo cada vez más consciente de los efectos negativos de los gases de efecto invernadero, la creciente escenarios de combustibles fósiles y los beneficios financieros de la eficiencia energética, el diseño de la oficina también ha comenzado a incorporar la sostenibilidad como un principio básico [20], [75].

Además de beneficiar al medio ambiente, la eficiencia energética y el recorte de los beneficios de residuos permite ahorrar una cantidad significativa de dinero que de lo contrario se desperdiciaría en facturas de combustible, costes de papelería y un "ahorro rápido" temporal compuesto por soluciones que en última instancia no solucionan los problemas de ineficiencia [20], [75].

La figura 12 resume en un eje cronológico los principales hitos en la historia de la tipología de espacios de oficina.

Figura 12. Evolución histórica de los espacios de oficinas.

3.2 Conceptos.

3.2.1 Concepto I. Espacio.

LA OFICINA CELULAR.

En la forma más tradicional de la oficina, la Oficina Celular, los despachos individuales y dobles se alinean a lo largo de pasillos, los cuales normalmente solo disponen de iluminación artificial, constituyendo únicamente espacios de circulación, entendidos como rutas de escape, que no permiten ser amueblados [10].

Suele ser la opción de empresas muy jerarquizadas en las que los procesos de trabajo se subdividen en muchos procesos de menor tamaño. Este tipo de oficina es sobre todo la expresión del estatus que el individuo ocupa dentro de la empresa a través del tipo de despacho que tiene [10], [85].

LA OFICINA DE PLANTA ABIERTA Y LA OFICINA DE GRUPO.

Las oficinas de planta abierta u oficinas de grupo son ideales cuando hay una alta necesidad de intercambio de información y comunicación, pero los requerimientos de concentración son bajos [10].

En su forma tradicional, en general, no gustan a los usuarios altamente cualificados y son contraproducentes para la concentración en el trabajo. Sin embargo, todavía atraen a empresas, debido a su alta eficiencia de uso del espacio, flexibilidad y apoyo de los procesos comunicativos [10], [85].

LA OFICINA MULTI-ESPACIO.

En la estrategia de uso conocida como el "concepto multi-espacio", el espacio de planta abierta se distribuye en zonas de trabajo abiertas y zonas comunes [10].

Estos espacios especiales fomentan las oportunidades de comunicación, así como las reuniones informales y el intercambio [10].

Los multi-espacios de oficinas están dotados con elementos de diseño acogedor que generan una calidad de ambiente hasta ese momento desconocida en oficinas de planta abierta [10].

Junto a los espacios de trabajo, los componentes clave son los espacios para reunión, comunicación y descanso. La tecnología se descentraliza, lo que reduce enormemente el tráfico de circulación en las zonas de trabajo [10].

Estos nuevos conceptos dan lugar a espacios con cualidades positivas que contribuyen a la motivación de los empleados y a un nuevo concepto de cultura corporativa [10].

LA OFICINA-COMBI.

La oficina-combi se desarrolló a finales de la década de 1970 en los países escandinavos. Combina las ventajas de la oficina celular y de la oficina de planta abierta, de ahí su nombre. Al mismo tiempo, evita en gran medida sus inconvenientes [10].

Los lugares de trabajo están situados directamente al lado de la fachada y se agrupan principalmente como despachos individuales en torno a una zona interior con iluminación indirecta, de las que están separados por paredes de vidrio de suelo a techo [10].

Cada lugar de trabajo tiene un espacio de reunión, una visión directa al exterior y luz natural, control individual del entorno de trabajo y la libertad de trabajar a puerta cerrada, pero sin estar aislado de los acontecimientos en la oficina y pudiendo abrir la puerta al resto de la oficina [10].

Este tipo de oficinas son ideales para procesos en los que hay un cambio constante entre necesidad de concentración individual y coordinación: el foco está en las sinergias y en el uso intensivo de las zonas comunes [10].

Además, las oficinas-combi incrementan la transparencia de los procesos de trabajo, la flexibilidad de la organización y pueden también ahorrar espacio [10], [57].

LA OFICINA FLEXIBLE. EL BUSINESS CLUB.

Las denominadas oficinas flexibles o business club avanzan un paso más allá que la oficina-combi en términos de uso flexible del espacio [10].

Gracias a la asignación personal de espacios, se da lugar a una gran diversidad de escenarios que se adaptan a los diferentes patrones de actividad, en lugar de individualmente a los empleados, pudiéndose utilizar de manera fija o a medida de cada situación [10].

Sólo unos pocos de estos escenarios basados en tareas deberían estar siempre reservados; la mayoría están libremente disponibles para la necesidad que surja en cada momento [10].

A pesar del alto coste de inversión inicial, el Business Club ofrece ventajas económicas a través de un considerable ahorro de espacio, del 20 al 40%, dependiendo de la proporción entre la superficie de trabajo y los empleados que la utilizan [10].

Este modelo de espacio de trabajo sólo es factible si una proporción de empleados combinan el trabajo en la oficina con trabajar desde casa [10].

Figura 13. De izquierda a derecha: Oficina Celular, Oficina de planta abierta o pradera, Oficina multi-espacio, Oficina-combi, Oficina flexible. (a) Despachos individuales (b) Zonas de trabajo (c) Zonas comunes. Fuente: elaboración propia.

3.2.2 Concepto II. Procesos.

EL ESPACIO DE CO-WORKING.

El modelo de oficina compartida de Nueva York sirve como punto de partida para la idea de ofrecer oficinas y salas de conferencias en base a la demanda y de duración determinada, donde el ocupante especifica individualmente el uso, los tiempos de alquiler y los servicios asociados, se ha implementado con éxito durante años por empresas grandes y pequeñas, regionales e internacionales [10].

Estos centros de negocios se caracterizan por su funcionalidad a través de un ambiente muy cuidado y por sus excelentes ubicaciones [10].

EL ESPACIO DE CLOUD WORKING.

Cada vez más empresarios se interesan por comenzar sus nuevos negocios en el sistema llamado cloud working para poder trabajar por su propia cuenta desde cualquier lugar simplemente con un dispositivo portátil con acceso a internet [10].

Ante la actual situación de crisis económica, el cloud working ofrece la oportunidad de poder trabajar con otros países y abrirse a mercados internacionales en auge como Brasil, Rusia o India, sin necesidad de trasladarse hasta allí [10].

En este punto, cabe destacar como ejemplo el caso de éxito de Telefónica en España. A inicios del siglo XXI, Telefónica consigue concentrar a sus 14.000 empleados (cerca del 30% del total en España) en una única sede [10].

El Distrito C (desde octubre de 2011 renombrado como “Distrito Telefónica”), ubicado en el barrio madrileño de Las Tablas, convirtiéndose así en la mayor sede corporativa de Europa [10].

Dicho proyecto, además de la construcción de unas instalaciones de tales dimensiones, también conllevaba un meticuloso control al desarrollo de un cambio de cultura empresarial y de la forma de los trabajar de los empleados [10].

El “Distrito Telefónica” dispone de 367.370 m² construidos: 170.238 son oficinas y otros 16.305 son para servicios. Dentro de esta última área citada hay unos 3.000 m² dedicados a un área de formación para 700 empleados [10], [118].

También hay una guardería con capacidad para 150 niños, abierta a todo el público, pero con preferencia y descuentos especiales para los empleados de Telefónica y familiares; un gimnasio con las mismas condiciones de uso, un centro médico en el que se hacen las revisiones médicas y campañas de prevención (éste dedicado únicamente a trabajadores) y un área comercial [10].

El proyecto es especialmente significativo para el Grupo Telefónica y no supone solamente un desplazamiento físico de personal, sino que pretende desarrollar una nueva cultura de trabajo [10].

La finalidad de Distrito C es fomentar esta novedosa filosofía laboral cuyos ejes fundamentales son: incrementar la proximidad entre directivos y colaboradores, impulsar el trabajo en equipo, fomentar las labores por funciones y objetivos y, finalmente, facilitar el intercambio de ideas, conocimientos y experiencias [10].

Los espacios externos han seguido una filosofía urbanística caracterizada por espacios abiertos, sin recintos, ni barreras arquitectónicas. Y, aunque el conjunto de edificios es diverso, se ha diseñado una marquesina que cubre las construcciones de baja altura y proporciona una idea de unidad [10].

En cuanto a los espacios interiores, se ha optado por orientarlos a partir de las funciones y tareas que desempeñan los empleados, es decir, están pensados para responder a las necesidades de las personas que van a ocuparlos. Por su parte, la tecnología es vista como una herramienta que facilita la nueva forma de trabajar en estos espacios habilitados en Distrito C [10].

La estrategia arquitectónica de unidad y funcionalidad se apoya en la definición de una serie de perfiles laborales para dotar al personal del espacio y las herramientas adecuadas en función de sus necesidades de trabajo [10].

De este modo, la variedad de perfiles se mueve en un rango que fluctúa entre aquellos con una movilidad muy alta, hasta los empleados que desempeñan tareas más o menos estáticas [10].

Para los puestos de trabajo de alta movilidad, donde la persona no está de forma continuada en su puesto de trabajo, desde Distrito C se les facilitan las herramientas adecuadas para realizar sus tareas tanto desde cualquier punto de la oficina, como la oficina del cliente o desde el propio hogar del empleado [10].

Este perfil personal dispone de teléfono móvil multifuncional, ordenador portátil y capacidad para trabajar con las redes inalámbricas o con la Red de Área Local (LAN) de las instalaciones [10].

Mientras que aquellos perfiles con menor movilidad, debido a que desempeñan su trabajo fundamentalmente en un puesto fijo, cuentan de base con un ordenador de pantalla plana de sobremesa y un teléfono fijo que funciona con tecnología IP [10].

Precisamente, la telefonía IP es una de las bazas tecnológicas del Distrito C. Gracias a este modelo de telefonía se potencia la movilidad dentro de todo el recinto, de tal forma que un usuario puede utilizar un teléfono IP desde cualquier punto sin necesidad de estar en su puesto de trabajo, tan sólo bastará con que se identifique y automáticamente la red le redirige todas las llamadas al lugar donde se encuentra [10].

En conclusión, en Distrito C, el Grupo Telefónica no pretende ligar a una persona a un determinado puesto y un espacio fijo, sino que éstos se definen en función de la interacción y la movilidad del personal, constituyendo un ejemplo paradigmático de tipología que combina las ventajas del modelo de oficina flexible o business club, espacio de co-working y modelo de cloud-working [10].

La empresa ha recibido numerosos reconocimientos y premios por la excelencia de sus programas y sus buenos resultados [10].

Figura 14. Imagen aérea del Distrito C de Telefónica. Distrito C supuso una inversión urbanística y empresarial de más de 500 millones de euros que contó con el diseño del arquitecto Rafael de la Hoz. Fuente: www.telefonica.com

AGILE WORKING.

Como ya se introdujo en el apartado 3.1 del presente capítulo, el modelo de trabajo *Agile* permite a los usuarios trabajar con las mínimas limitaciones y la máxima flexibilidad [10].

Se implementa en la totalidad del espacio de trabajo, y los usuarios pueden elegir el lugar donde prefieren trabajar, ya sea un puesto de trabajo tradicional, un puesto de trabajo alto para estar de pie, un espacio de descanso o incluso la cafetería [10].

En un entorno de trabajo *Agile*, los empleados pueden preferir trabajar desde casa o en un café local, por ejemplo. Se trata de ser lo más abierto y flexible posible en el enfoque de la empresa sobre dónde y cuándo trabajan las personas [10].

Establecer una cultura más autónoma con *Agile* puede ser un verdadero impulso para atraer y retener al mejor talento. Tiende a considerarse una fuente de ventaja competitiva para los empleadores, así como un beneficio para los empleados, aunque es esencial contar con una infraestructura de tecnología adecuada para que funcione [10].

Entre las principales ventajas de este sistema, cabe destacar la mayor sensación de autonomía y libertad para los usuarios, así como el aumento de satisfacción en el trabajo, resultante de un mayor compromiso y retención de talento. Por otro lado, disminuye la necesidad de superficie, reduciendo así los costes de operación [10].

Sin embargo, es un sistema que presenta algunos retos a su vez, siendo el principal el hecho de requiere un cambio cultural para empleados y directores [10].

Asimismo, cuando se aplica a todo el negocio los empleados no puede optar por no participar. Por último, como ya se ha indicado, se trata de un modelo que requiere tecnología e infraestructuras adecuadas para su funcionamiento [10].

ACTIVITY BASED WORKING (ABW).

Activity based working responde al concepto de usar configuraciones diferentes para diferentes tareas en el espacio de trabajo [10].

A menudo se diseña en torno a una oficina abierta, compuesta de una variedad de espacios de trabajo alternativos donde los usuarios pueden elegir, incluidos los espacios comunes, habitaciones tranquilas, cabinas de colaboración, espacios para reuniones o zonas de descanso [10].

A menudo se utiliza en un entorno de trabajo *Agile*, ya que proporciona flexibilidad y opciones, y puede funcionar bien cuando se combina con *hot-desking* [10].

Las empresas que han adoptado el modelo *Activity based working* reportan un aumento en la productividad, ya que los empleados pueden elegir trabajar en el área de trabajo que más se adapte a la tarea en cuestión [10].

Entre las principales ventajas cabe destacar la posibilidad de elección entre una variedad de espacios de trabajo, el aumento de la autonomía de los usuarios y potencial de incremento de su productividad [10].

Además, los usuarios están físicamente más activos durante la jornada de trabajo [10].

En contraposición, algunos de los retos que plantea este modelo es la dificultad de ser ajustable a cualquier tipo de empresa o puesto de trabajo, ya que requiere un cambio de cultura y gestión del cambio [10].

HOT-DESKING.

El *hot-desking* consiste en la práctica de tener puestos de trabajo no asignados, de manera que varias personas puedan usar cualquier estación de trabajo [10].

Funciona bien en entornos en los que no todos deben estar en la oficina al mismo tiempo o donde hay una variedad de posibles configuraciones espaciales en las que los usuarios pueden elegir dónde trabajar. Esto permite que el espacio en planta se use de la manera más eficiente posible [10].

Un ejemplo radical de estas nuevas oficinas de "teletrabajadores" se presenta en la oficina de British Telecom en Stockley Park, ubicado cerca del aeropuerto de Heathrow [10].

Diseñado por DEGW en 1996, el diseño de planta completamente abierta resultó ser incluso más abierto que la oficina de *tayloriana*, ya que todos los espacios de trabajo estaban abiertos, sin oficinas separadas [10].

Este nuevo plan repartía a 3.000 empleados entre 1.300 puestos de trabajo, lo que refleja la fuerte apuesta de British Telecom por el trabajo a distancia [10].

Con la mudanza a Stockley Park, se alentó a los empleados a trabajar desde su casa o con sus clientes hasta por tres días a la semana, yendo sólo dos días a la oficina [10].

Combinado con el fenómeno relativamente nuevo del *hot-desk*, donde se alentaba a los empleados a usar un puesto de trabajo cada día, esto permitió a British Telecom ahorrar espacio, vender bienes inmuebles en propiedad en áreas urbanas, utilizar una nueva tecnología de comunicación para ahorrar dinero y promover un ambiente de trabajo más flexible [10].

Con todo, estos avances en el diseño de oficinas buscaron cambiar por completo la cultura de trabajo de la organización [10].

Aunque esta nueva forma de diseño de oficina tenía intenciones positivas, como ahorrar costes, permitir una mejor flexibilidad y alentar una mayor colaboración, aún tenía inconvenientes [10].

En el entorno real de la oficina, esta organización dificultaba que los empleados se identifiquen con la corporación, lo que impacta negativamente en su bienestar y productividad [10].

3.3.3 Concepto III. Espacio, procesos y personas.

FLEXIBLE.

El concepto de trabajo Flexible es el término utilizado por Recursos Humanos para referirse al derecho legal de los trabajadores de solicitar un modelo de trabajo alternativo a la norma empresarial [10].

Puede incluir trabajar en un horario diferente o trabajar desde casa, y se solicita y se acuerda de forma individual [10].

Acordar trabajar de forma flexible caso por caso puede proporcionar a los empleados la oportunidad de ser más productivos, al tiempo que aumenta su compromiso y satisfacción laboral [10].

Crear una cultura de elección y flexibilidad en el lugar de trabajo lleva mucho tiempo y atención. Estas estrategias en el lugar de trabajo pueden funcionar de manera brillante en algunas organizaciones, aunque no son adecuadas para otros [10].

La clave es identificar una estrategia de trabajo que se adapte al negocio y luego diseñar el espacio de oficina a su alrededor [10].

Además, esta organización puede verse impulsada por un espacio de trabajo diseñado en consecuencia, tal como se describe en el apartado 2.1 de este capítulo.

EXPERIENCIA DEL EMPLEADO.

A lo largo de la evolución del diseño de oficinas en los últimos 200 años, se han visto muchos elementos de diseño que llegan, salen, resurgen y se reutilizan.

Desde la oficina *tayloriana* hasta la granja de cubículos, la mayoría del diseño de oficinas ha sido una extensión de la ética empresarial capitalista: productividad, rentabilidad y crecimiento.

Sin embargo, todos los elementos relacionados con el bienestar en el lugar de trabajo, cuando se combinan, ilustran hasta qué punto se ha convertido el empleado en el centro del proyecto de diseño de la oficina [38].

Las empresas se están dando cuenta de que la productividad comienza con los productores, desde los gerentes en la parte superior hasta los aprendices en la parte inferior.

La clave para aumentar su productividad no se trata de soluciones rápidas, ni de empujar a la mayor cantidad posible de personas en filas de cubículos, o de incorporar una configuración de *hot-desk* no funcional.

El camino a seguir para las empresas es cuidar de sus empleados, nutrir su crecimiento, alentar su desarrollo de habilidades y luego retenerlos [16].

La evolución del diseño de la oficina comenzó con el modelo industrialista de la línea *taylorista*, y poco a poco se ha vuelto algo completamente diferente.

Las decisiones relacionadas con la distribución y el diseño de los lugares de trabajo ya no se basan en la propiedad, sino que están cada vez más influenciados por Recursos Humanos, siendo los objetivos clave retener y atraer al mejor talento del mercado.

Tal como se detalla en los párrafos anteriores, los elementos más importantes y básicos del éxito de la empresa se encuentran en el cuidado de los empleados, y el espacio de oficina puede ser un facilitador de ello [16], [38], [52].

WELLNESS.

Tal como se detalla en el apartado 2.1 del presente capítulo, las iniciativas de bienestar en el lugar de trabajo no solo ahorran dinero al aumentar la productividad y reducir el absentismo, sino que también hacen que el personal se sienta valorado y produce un equipo mucho más efectivo, cohesivo y motivado de lo que existiría de otra manera [38].

Debido a esto, muchas empresas con visión de futuro han tomado en cuenta los cambios necesarios para mejorar el bienestar en el lugar de trabajo al diseñar y equipar un nuevo espacio de oficina [16], [38].

Los empleados están experimentando multitud de problemas diferentes que tienen un impacto negativo en su bienestar, incluyendo una dieta deficiente, falta de ejercicio, sobrepeso y beber demasiado alcohol. Para combatir esto, las empresas están estudiando diferentes métodos que pueden incorporarse en el lugar de trabajo [16], [38].

Las cafeterías que promueven comidas y tentempiés más saludables, fruta gratis, iniciativas de ejercicio físico suave en el trabajo, membresías en gimnasios y oficinas que invitan a la relajación y fomentan el movimiento son algunos de los diferentes elementos que se incorporan en los espacios de oficinas para promover el bienestar [16], [38].

Junto con estos cambios diferentes y sutiles, se incluyen elementos de diseño de oficina progresivos y variados, como salas informales y "divertidas", espacios de colaboración, habitaciones para relajarse, muebles ergonómicos especializados y acceso a la tecnología más actual y eficiente [16], [38], [90].

4. SALUD, BIENESTAR Y PRODUCTIVIDAD

4.1. Síndrome del Edificio Enfermo.

La Agencia de Protección Ambiental estadounidense define el Síndrome del Edificio Enfermo (SEE) como “situaciones en las cuales los ocupantes de edificios experimentan efectos de salud y comodidad que parecen estar relacionados con el tiempo que pasan dentro del edificio y que desaparecen cuando abandonan el mismo”.

Los síntomas que caracterizan el SEE incluyen “dolor de cabeza; irritación de ojos, nariz y garganta; tos seca; piel seca; mareos y náuseas; dificultad para concentrarse; fatiga; y sensibilidad a los olores [11], [157].

La aparición del Síndrome del Edificio Enfermo se ha relacionado durante mucho tiempo con la reducción de la ventilación en edificios, impulsada por el deseo de aumentar la eficiencia energética en los años 70 y 80.

Los estudios muestran que el SEE es probablemente el resultado de una serie de características de construcción, siendo las más comunes los niveles bajos de aire fresco y los altos niveles de contaminantes en interiores [48].

El alcance del SEE ha sido importante, ya que la Organización Mundial de la Salud, en 1990, informó que el 30% de los edificios en todo el mundo pueden tener ambientes interiores que contribuyen al SEE.

Aunque los informes de SEE han disminuido en los últimos años, el problema aún persiste. Como señala Heerwagen en 2010, otras investigaciones muestran que hasta un 20% de los trabajadores pueden verse afectados [94].

Las soluciones para el diseño y operaciones de edificios incluyen la reducción de las fuentes de contaminantes y más y un mejor aire ventilado.

Además, si se aumenta la ventilación de los edificios para mantener los niveles de dióxido de carbono en el interior similares a los niveles al aire libre, los síntomas de SEE se reducirían en un 70-85% [92].

El potencial de negocio de los espacios de trabajo más saludables es demasiado grande como para ignorarlo. Fisk [157] estima que en los EE. UU. “el ahorro anual potencial y el aumento de la productividad son de 6 a 14 mil millones de dólares por reducción de la enfermedad respiratoria, de 1 a 4 mil millones de dólares por alergias reducidas y asma, de 10 a 30 mil millones de dólares por síntomas reducidos del Síndrome del Edificio Enfermo y 60 mil millones por mejoras directas en la productividad de los trabajadores que no están relacionadas con la salud [158].

4.2. La relación entre salud, bienestar y productividad.

Una creciente evidencia indica un vínculo entre la productividad y el bienestar de los empleados. Un examen de los programas de salud y productividad de más de 350 empresas con más de 1.000 empleados muestra que las empresas que incorporan salud, bienestar y productividad en sus estrategias comerciales logran resultados financieros notablemente mejores [52].

La Fundación Europea para la Gestión de la Calidad (EFQM) es una organización sin ánimo de lucro, fundada en 1988 por 14 importantes compañías europeas, con el apoyo de la Comisión Europea. Su Misión es ser la fuerza que impulsa a la excelencia en las organizaciones europeas de manera sostenida [164].

El modelo EFQM es un modelo de gestión, es decir, un marco de trabajo que sirve de referencia a las organizaciones para compararse con el fin de conseguir la excelencia [164].

El modelo EFQM de Excelencia es un marco de trabajo no prescriptivo, con lo cual cada organización puede adaptarlo “a medida”. Se compone de nueve criterios, cinco de ellos son los denominados “Criterios Agentes”, que se refieren a todo aquello que la organización hace; y los cuatro restantes son los “Criterios Resultados”, que abordan todo lo que la organización logra [164].

La Figura 15 muestra el peso que en el modelo EFQM tienen los parámetros relacionados con bienestar y personas, con un notable impacto en los resultados.

Figura 15. Modelo de Excelencia EFQM. Fuente: Prof. Serio Vega Sánchez.

Las organizaciones que pusieron en práctica programas efectivos en salud y productividad lograron rendimientos para los accionistas en un plazo de cinco años de más del 14.8%, mientras que para las empresas sin programas efectivos los rendimientos disminuyeron en un 10.1%.

Además, las empresas con programas eficaces de salud y productividad tuvieron una tasa de rotación del 15%, mientras que en las que no tuvieron, la tasa más alta del 21% [173].

El rendimiento laboral está estrechamente relacionado con el bienestar del empleado; el malestar aumenta sustancialmente la probabilidad de resultados comerciales negativos, que pueden ser observados en forma de costes directos relacionados con la salud, así como el deterioro del rendimiento comercial.

A título indicativo, los empleados con un bienestar deficiente reportan:

- 2 veces más probabilidades de tener altos costos de reclamos de atención médica [141]

- 4 veces más probabilidades de tener visitas a emergencias y días de incapacidad a corto plazo [141]
- 7 veces más probabilidades de tener un bajo rendimiento laboral [141]
- 2 veces más probabilidades de estar ausente [141]
- 2 veces más probabilidades de tener baja intención de permanecer con el mismo empleador [141]

Existe una relación estadísticamente significativa entre los programas exitosos de salud y productividad propugnados por Recursos Humanos y la rentabilidad de las empresas, entendida como: mejores resultados comerciales, menores gastos médicos, una mejor efectividad de la tarea, y reducciones del tiempo perdido [52].

Todo lo anterior conduce a un mayor rendimiento de las ventas [52].

Si bien existe una relación entre los factores de estrés en el interior y la comodidad, la salud y la productividad de quienes usan los edificios, las formas de medir esto no son definitivas ni están plenamente establecidas.

Es un campo de estudio en desarrollo y Bluysen afirma que un mayor enfoque debe estar "en los usuarios en lugar de componentes individuales y en el que el objetivo es mejorar la calidad de vida en lugar de evitar que la gente se enferme o se sienta mal "[16].

En general, hay evidencia de que las personas sanas y felices son más productivas y que los edificios afectan nuestra salud mental y física. Sin embargo, existe una necesidad de más investigación, estudios de casos industriales y esfuerzos de comunicación para elevar la relación entre las personas y los edificios [16].

No obstante, es evidente que la calidad del edificio no es el único factor que impacta la salud y el bienestar de las personas. Las políticas corporativas en el lugar de trabajo juegan un papel importante.

Por lo tanto, es necesario que haya una acción más coordinada entre los gerentes de las instalaciones, los recursos humanos, la responsabilidad social corporativa y los departamentos de sostenibilidad [29].

En palabras de Rick Fedrizzi, Chairman and CEO International WELL Building Institute, "la sostenibilidad y la salud son sinónimos. Es por eso que estamos colaborando con líderes de sostenibilidad ambiental en Europa y más allá, para acelerar no solo la transformación del mercado, sino también la transformación humana. Solo juntos podremos conducir esta segunda ola de sostenibilidad hacia un futuro más brillante y saludable" [43].

Asimismo, desde la institución Urban Land Institute, en el evento Emerging Trends in Real Estate Europe 2016, se afirmó que "el claro desafío para la industria es ser menos sobre ladrillos y mortero y más sobre el servicio. Hace veinte años teníamos inquilinos, ahora tenemos clientes. En 20 años, tendremos invitados" [55].

Por último, apoyando esta evidencia, Jan Karel Mak, CEO of Deerns sentencia: "un edificio sostenible debe ser eficiente desde el punto de vista energético, sin embargo, un edificio que mejora la productividad ofrece ahorros mucho mayores" [22].

Por lo tanto, "la integración de ambas características impulsará tanto la reducción de emisiones de gases efecto invernadero como los beneficios del ciclo de vida económico, para su mutua ventaja" [22].

Difícilmente puede haber algo más importante que nuestra propia salud y bienestar, y el de nuestros seres queridos. Mientras tanto, para la mayoría de los empleadores, una fuerza laboral saludable y feliz es un componente vital de un negocio productivo y exitoso a largo plazo.

Los costes de personal, incluidos los salarios y los beneficios, generalmente representan aproximadamente el 90% de los ingresos de una empresa. De ello se deduce que la productividad del personal, o cualquier cosa que afecte su capacidad para ser productivos, debe ser una preocupación importante para cualquier organización.

Lo que puede parecer una mejora modesta en la salud o productividad de los empleados, puede tener una implicación financiera significativa para los empleadores. Esta ecuación está en el corazón del caso de negocio para oficinas saludables y productivas

Existe evidencia abrumadora que demuestra que el diseño de una oficina afecta la salud, el bienestar y la productividad de sus ocupantes. Para muchos lectores, eso suena tan obvio que casi no hace falta decirlo. Pero es necesario decirlo, alto y claro, porque esta evidencia aún no ha tenido una gran influencia en el sector inmobiliario principal, y aún no se está traduciendo a escala en decisiones de diseño, financiamiento y arrendamiento, ciertamente no en todas partes del mundo.

Además, nuestra comprensión de las implicaciones para la salud, el bienestar y la productividad del diseño de oficinas se está profundizando, ayudada por los avances en tecnología y una creciente concienciación entre un pequeño número de desarrolladores, propietarios e inquilinos ilustrados.

Por ejemplo, cada vez es más claro que existe una diferencia entre los entornos de oficina que simplemente no son perjudiciales, es decir, la ausencia de "malos", y los entornos que fomentan de manera positiva la salud y el bienestar, y estimulan la productividad.

5. ANÁLISIS CUALITATIVO DE CASOS DE ESTUDIO. JAPÓN

5.1. Introduction.

With intellectual productivity as economic and social factors core, the purpose of this qualitative study is to clarify the relationship between Green Office Buildings, workplace productivity, and the impact of efficiency in the Triple Bottom Line (people, planet, profit) related to social, environmental and economic sustainability.

The association between Green Office Buildings and workplace could contribute to increased **employees'** productivity through indoor environments and wellbeing in workplace, and the improved productivity impacts directly into the Triple Bottom Line objectives [21].

However, because of the chosen research approach, the research results may lack generalizability.

The assumption, on which this paper is approached, is that exist some indicators in Green Office Buildings design that may provide an efficient method of improving the indoor conditions. This approach can potentially lead to performance gains for the organization and increasing well-being, creativity, and productivity among the workforce.

This study fulfils an identified need to study what characteristics of sustainable design have the greatest effect on increasing productivity. Users' wellbeing and workplace productivity impact directly in social and economic sustainability and become key aspects of Sustainable Facility Management.

In the Facility Management (FM) industry, sustainability is increasingly an important focus in businesses' decision processes, and it is becoming a critical part of current and future decisions on new office designs and locations [74].

According to a Global Reporting Initiative, which monitors the development of sustainability regulations in over 180 countries, an increasing number of organizations are reporting their sustainability performance [74]. Sustainability will cover the Triple Bottom Line dimensions in the FM industry's future role basing on:

- 1) People – Social Sustainability: Health issues: Environmental and workplace health, comfort conditions and well-being.
- 2) Planet – Environmental sustainability: Natural resource preservation, climate change (energy efficiency), and pollution.
- 3) Profit: - Economic Sustainability Sound and ethical business and regulation practices. Productivity improvement becomes a key issue.

Figure 16. Facility Management industry's future role conceptual model. Source: Self-made based in ISS World Services A/S, Copenhagen Institute for Future Studies (CIFS), 2013. *ISS 2020 Vision: New Ways of Working - The Workplace of the Future*, Soborg, Denmark: ISS World Services A/S [74]

Productivity is that which people can produce with the least effort [128]. Productivity is simply defined by Sutermeister as output per employee hour, quality considered [152]. Dorgan defines productivity as the increased functional and organizational performance, including quality [36].

An increase in performance is expressed in a directly quantifiable reduction of absenteeism. The improvement in performance can, however, also be the result of an increase in the quantity and the quality of the production during the period that employees are actively working [126].

The high productivity of the employees is a competitive advantage in the corporate world nowadays. To achieve this, the employees need both physical as well as mental health, growth in an environment to support them at the time of work and provide them with the necessary emotional capacity to interpret and experience events in a way that leads to positive and productive actions [183].

Good workplaces help people to get deeply involved in their work, providing them all what they need to enjoy well-being at work. The outcome could be perpetuated: a systemic sensation of the well-being that spread easily, boosting individuals, teams and whole company performance [147].

In this study, we aim to clarify how the increasing of productivity influence directly in the Triple Bottom Line objective within a Sustainable Facility Management strategy, through a quantification methodology applied in four study Scenarios. Therefore, techniques that increase productivity in green offices are in high demand.

The present study shows four Case Studies where the increment of productivity has been quantified. In each Scenario, we indicate the date and the authors of the experiment.

The selected Study Scenarios represent outstanding achievements in its time in the construction of Green Offices Buildings in Japan.

5.2. Implementation of economic evaluation on intellectual productivity.

Figures 17 and 18 show the evaluation range of intellectual productivity and four intermediate indicators. The assessment range is based on the intellectual activities classified into three hierarchies [64], [67], [68], [69].

Figure 17. Outline of Intellectual Productivity Evaluation System. Source: Professor Ikaga Laboratory.

Figure 18. Relationship between additional rent and economic effect. Tsubo is a Japanese unit of area (1 tsubo= 3.3 sqm). Source: Professor Ikaga Laboratory.

As a cost-effective evaluation, targeting the Company's goals, four intermediate indicators on intellectual productivity were transferred into Comprehensive Assessment System for Built Environment Efficiency (CASBEE) evaluation [101].

This formula shows the effect given, the additional rent rate [%] for relocation to a new building or a reformed building with sustainable design criteria.

$$\text{Intermediate Indicators [\%]} = W_1A_1 + W_2A_2 + \dots + W_nA_n = \sum N_{ij}A_{ij}$$

Formula 1. The method of calculation of intellectual productivity. Source:
[Murakami, et al., 2014]

Where W_{ji} is the weighting coefficient of each element of evaluation. This W-factor is calculated using subjective evaluation by questionnaire. A_{ji} represents the standardized score of each item of evaluation.

According to Formula 1, is possible to estimate the economic value of the intellectual productivity improvement. Based on the productivity concept, evaluation should be expressed as a cost ratio. This indicator is described as:

$$\text{Productivity Evaluation Index} = \frac{\text{Profit (Conversion Expenses for Improvement of Work Efficiency)}}{\text{Investment (Expenses for Improvement of Work Efficiency)}} \times 0.10$$

Formula 2. The method of calculation of Productivity Evaluation Index.

Source: self-made.

This is a commonly used index in Japan in recent years, based on Return of Investment formula, as an index to measure the profitability of companies' businesses, assets, and facilities, and it is necessary to evaluate and verify the adequacy of investment from a management / financial perspective [144], [149], [150], [156].

The productivity evaluation index can be one of the indicators of investment performance or investment efficiency.

KAJIMA CORPORATION TECHNICAL RESEARCH INSTITUTE (KATRI), TOKYO.

Figure 19. Outside view of Kajima Corporation Technical Research Institute (KaTRI), Tokyo.

Figure 20. Inside view of Kajima Corporation Technical Research Institute (KaTRI), Tokyo.

Table I. Kajima Corporation Technical Research Institute Building Outline.

Design	Kajima design
Construction	Kajima Corporation (Tokyo Architectural Construction Branch)
Number of stories	One basement, five stories, one penthouse
Structure	Reforced concrete
Site area	5,256.68 sqm
Building area	2,202.39 sqm
Floor area	8,913.73 sqm
Building height	18.14 meters
Construction period	April 2010-June 2011
Start of using	October 2011
CASBEE	S rank BEE score 8.3 points (highest value in Japan at the time of completion).

This Study Scenario is selected because it is one of the few examples of rehabilitation of an existing building, which counts with numerous Architecture Awards.

Kajima Corporation presents a new concept to Green Office Building, as economical and suitable way for work style. This building was renovated concurrently with the re-development Project in front of Tobitakyu Station in Chofu City, a suburb of Tokyo.

It comprised offices for three hundred researchers and was connected with the laboratories building (completed in 2008) for integral use. The main objectives of the project were: to encourage interaction between researchers at the workplace, low initial investment, and leading project for the realization of a ZEB (Zero Energy Building).

Regarding the relationship between this building and the concept of productivity, it is worth mentioning three key aspects that were considered in the design [98]:

- Knowledge creation. It is aimed to realize the next generation workplace, that flexibility responds to diversifying researchers' work style and simultaneously concentrates and cooperates. This is an office space with a balance of concentration and cooperation, energy conservation, and comfort.

- Kajima Technology. Apply technologies carefully selected from among developments technologies. It is a place to make technology leap that demonstrates and evaluates in the future, and it can be viewed as a live show case of technology. By applying many technologies, the building supports the comfortable environment of the next generation workplace, and through demonstration and evaluation, Kajima will further develop new technologies. The building fulfills the function of a live showcase that makes visitors experience technologies at the experiment and demonstration places with the building itself as a test facility.

It is a pillarless space of 80 x 11 meters that can flexibly respond to changes in experiment contents and future needs laboratory changes.

In the six-layer spill space adjacent to the needs laboratory, exchange among researchers and various direct ways of working were encouraged. A message to the Community. The building is helping to conserve regional ecosystems considering biodiversity.

The project inherits the water of Musashino Forest and Tama River, contributing to society and the community by harmonizing with the local environment.

Aiming for harmony with the local environment and symbiosis with wildlife is created an urban greenery zone to provide comfort to residents and research staff members, to achieve energy saving effects and harmony with the surrounding environment [138].

To evaluate the increase of productivity in the building, several experiments have been carried out based on the methodology previously explained.

“Research single seat,” extract researchers’ creative capability in an organic space that concentrates and relaxes, personal thought and communication compatibility.

“Selective workplace,” it gives selectivity to seat placement and partition height, and it corresponds to the diversity of work style.

“Place of knowledge reflux,” communication HUB will be established as a place where researchers can interact with each other beyond belonging and specialized fields and stimulate ideas daily and contribute to the creation of knowledge network musings.

In this project, it was important to achieve energy conservation and low carbon emission while maintaining workplace productivity in an office building. The results of the experiments showed the high acceptability for the environment and the same level of productivity before reconstruction [98].

SHIMIZU CORPORATION OFFICE HEADQUARTERS, TOKYO.

Figure 21. Outside view of Shimizu Corporation Office Headquarters, Tokyo. Source: www.shimz.co.jp

Figure 22. Inside view of Shimizu Corporation Office Headquarters, Tokyo. Source: www.shimz.co.jp

Table II Shimizu Headquarters building outline.

Site area	3,000 sqm
Building area	2,200 sqm
Floor area	51,800 sqm
Number of stories	Three basements, 22 stories, 1 penthouse
Building height	110 meters
Structure	Reinforced concrete (partial steel frame) seismic isolation structure
CASBEE	S rank BEE score 9.7 points (highest score ever achieved)

The company headquarters building was planned to realize ZEB in the super high-rise office in the urban area, strengthen BCP function, and improve intellectual productivity.

This Head Office was Japan's first high-rise office higher than 100 meters to incorporate a reinforced-concrete seismic isolation structure. The primary motives for this choice were twofold: to create a building that has outstanding seismic performance that can serve as a disaster-relief facility, and, create column-less space that maximizes office flexibility.

Furthermore, the main goal in designing Shimizu Office Headquarters was a 50% reduction in annual CO₂ emissions about 2005 ordinary office buildings in Tokyo [5].

Seeking to create a building capable of withstanding disasters while striking a balance between energy conservation and comfort, Shimizu researchers developed many state-of-the-art technologies that lead the way toward a sustainable society.

Traditional reinforced-concrete structures deploy thick columns in a grid pattern, resulting in less than ideal conditions to create wide open office space. In contrast, the pre-stressed concrete perimeter frame of the Head Office and the reinforced concrete seismic isolation structure require no columns: no columns around the Windows.

These results in 12% more efficient usable space per floor than in structures with columns [142].

The column-less design of the work floors provides freedom and flexibility to configure layouts and expand the adequate available space. To maximize the use of these features, designers created workplaces that serve as catalysts for craftsmanship. Flows of movement promote communication and collaboration.

Each typical floor consists of three areas: work area, collaboration area, and support area. Interaction and flows of movement between these areas encourage new modes of communication and cooperation.

Also, 3.6-meter work desks have been chosen to allow two or three individuals, depending on their job roles, to sit at a single desk to improve communication.

NIKKEN SEKKEI LTD. OFFICE HEADQUARTERS, TOKYO.

Figure 23. Outside view of Nikken Sekkei Ltd. Office Headquarters, Tokyo.

Figure 24. Inside view of Nikken Sekkei Ltd. Office Headquarters, Tokyo.

Table III Nikken Sekkei Headquarters building outline.

Site area	2,583.00 sqm
Building area	1,497.75 sqm
Floor area	20,580.88 sqm
Number of stories	14 stories, one basement floor, one penthouse
Building height	69 meters
Structure	Steel frame construction, partially steel-framed reinforced concrete

The design aims to create a worthwhile entity. This office was intended to be a "factory" to produce such genuine, where the staff was constantly in direct contact with the reality and engages close communication with the others.

The building was not only simple and practical but genuine in every aspect such as facade, plan, details, and engineering, to be appropriate to a design office.

Working area and meeting area were laid out to enhance further the communication between the staff, which was considered as the focal point in the workplace.

A typical floor without ceiling allowed extension of separate space and improved the inspiration of the staff. Outside electro-motion shade, natural ventilation system, double layer electric heater glass and balcony at the east and west reduce heat load and assure pleasant environment. The general floor plan clearly parted work area of 1,000 sqm.

The work area consisted of individual workspace at the side and common area in the center.

The individual workspace is a both form to concentrate on a job. On the other hand, the common area is open to information to the others. The open space in the center had series of meeting tables, which serve as a place for small in-house meetings.

The white boards adjacent to the meeting tables will be a place for brainstorming or discussion with pinning up sketches or drawing on [104], [105].

NISSAN OFFICE HEADQUARTERS, YOKOHAMA.

Figure 25. Outside view of Nissan Office Headquarters, Yokohama.

Source: <http://www.nissan-global.com>

Figure 26. Inside view of Nissan Office Headquarters, Yokohama. Source:

<http://www.nissan-global.com>

Table IV. Nissan Headquarters building outline.

Start of using	2011
Floor area	92.102 sqm
Construction period	01/2007-04/2009
Design	Corporation Architectural Design Institute Taniguchi
Construction	Shimizu Corporation.
Number of stories	Two basements, 23 stories
Structure	SRC concrete
Building height	9.4 meters
CASBEE	Level 5

This case was the first in Japan of application in a real office of the Smart Productivity Evaluation System [73], which makes possible to convert into a contribution to economic value (yen/month x tsubo) to work efficiency, knowledge creation and employee motivation.

The main goal was to create a building that represents the universal value of Nissan as an automobile manufacturer. To this target, the idea of design is based on the concept of "a place of creation of knowledge" [73].

The building is set up by a two-level atrium and stairs on the north and south sides. The visual and spatial connection in this vast space is conceived as a facilitator of communication and prompt action, turning this space into a source of inspiration.

Workspaces are arranged transversely across the atrium to the north and south, with sufficient flexibility to increase or decrease the scale depending on dependency needs. The offices open to a panoramic view, to provide a bright and pleasant atmosphere for the worker.

Furthermore, in the environment/equipment plan, natural day lighting and natural ventilation were actively carried out in all offices, especially the communication zone, and workers were given a change in consciousness and behavior such as concentration and relaxation.

Enabling environmental operations such as control of blowing air volume of under floor air conditioning and opening and closing of natural ventilation openings in conference rooms and establishing ICT (Information and Communications Technologies) environments where work can be carried out anytime and anywhere. To improve workers' satisfaction was possible to select a place to work within various settings.

5.3. Discussion.

KAJIMA CORPORATION TECHNICAL RESEARCH INSTITUTE (KATRI), TOKYO.

This experiment was carried out by Kajima Technical Research Institute in collaboration with Tokyo University of Japan in 2008. The relationship between productivity and workplace was studied, following the method described in the present article.

The architecture variables selected for the experiment were: the thermal environment for each season, the light, and the sound environment.

The average value of responses on improving workability based on environmental improvement was compared (Table VI). Although the satisfaction level of the sound environment remained unchanged in the result of the experiment, the environmental satisfaction level average of light environment, thermal environment, and air quality were improved.

The environmental evaluation outline was reported, and then, intellectual productivity before and after the reconstruction was compared. The acceptance of resident's environmental factors is high, in most cases exceeding 80% of employees' productivity improvement perception due to environmental improvement decreased with the passage of time, but productivity tends to gradually improve [98].

There was a tendency that work efficiency and the satisfaction level were improved except the sound environment, and it was considered that the rebuilding effect appeared.

Figure 27. Comparison of Satisfaction with Environmental Elements at Nissan headquarters. Source: Self-made based on Plan and Workplace Environmental Evaluation of a Low-carbon Office (Part 6): Survey on Indoor Environment and Productivity and Evaluation of Reconstruction.

Table V. Average Satisfaction Improvement at Kajima Institute. Source: Self-made based on "Plan and Workplace Environmental Evaluation of a Low-carbon Office (Part 6): Survey on Indoor Environment and Productivity and Evaluation of Reconstruction."

Light environment	Thermal environment	Air quality environment	Sound environment	Total improvement
6.25 %	12.5%	18.75%	0	9.38%

Table VI. Average Work Efficiency Improvement at Kajima Institute. Source: [Miura, et al., 2013]

Spring (N= 125)	Summer (N= 101)	Autumn (N= 103)	Winter (N= 96)
17.6 %	17.1 %	16.7 %	15.4 %

SHIMIZU CORPORATION OFFICE HEADQUARTERS, TOKYO.

According to the results, 43% of employees experimented that the new office indoor environments improved their [136]. The results shown here are from the experiment carried out by Shimizu Corporation in 2014.

Regarding concentration, in the new headquarters, the percentage that answered, "easy to do" ("somewhat easier" + "easy to do" + "very easy") was 63%, compared with the 43% that answered the same in the old headquarters.

Meanwhile, the percentage of respondents who answered, "hard to do" is as low as 9% at the new head office, so the easiness of concentration in the office building was considerably improved.

The percentage of respondents who answered, "easy to do" regarding easiness of relaxation at the new headquarters and the proportion of respondents who said, "hard to do" were 37% and 28%, respectively.

The percentage of responding "easy to" for easiness of communication was 21% in the old head office, whereas at the new head office it was 53%, which means an increment of 32%.

On the other hand, the percentage of respondents who answered, "difficult to do" was 14% at the new headquarters, 20% less than the 34% of the former headquarters.

The percentage that answered, "easy to do" for the creative activity easiness was 44% in the new headquarters and 34% in the old headquarters.

Moreover, the percentage of respondents who answered, "hard to do" was 42% at the old headquarters, but at the new headquarters 13%, meaning 29% decrease. Therefore, at the new headquarters, it was considered that the "difficulty" of creative activities was considerably improved as compared with the old headquarters.

The satisfaction rate of the new headquarters was 67%, an increase of 47% from 20% of the old headquarters. The dissatisfaction rate was 13%, which was 30% lower than 43% of the former headquarters.

From this, it was considered that the overall satisfaction level for the new headquarters was significantly improved compared to the old headquarters.

Table VII. Average Satisfaction Improvement at Kajima Institute. Source: Self-made based on "Study on Urban High-Rise Office Building driving for ZEB. (Part 17). Effect evaluation of indoor Environments on Satisfaction and Productivity."

Concentration	Relaxation	Communication	Creativity	Whole building
23%	9%	32%	10%	47%

NIKKEN SEKKEI LTD. OFFICE HEADQUARTERS, TOKYO.

In this discussion, productivity evaluation at the model Scenario results from the experiment carried out by Nikken Sekkei Ltd. in collaboration with Daikin Systems Research Institute, Matsushita Electric Works, Johnson Controls and Musashi Institute of Technology are presented [149].

The difference between the evaluation value before and after the transfer was calculated, and the relationship between indoor environment, work efficiency, and satisfaction was examined.

The correlation coefficient between total working effectiveness and overall satisfaction was 0.855, which is very high. Assuming the overall satisfaction level was high, overall working efficiency would increase, and in Scenario that overall working efficiency improves, overall satisfaction would increase.

Self-evaluation overall work efficiency was evaluated as an average improvement of 4.7% compared with before relocation. Adopting this value, and if the annual income per capita was 5 million JPY, and the office occupancy area of 3.03 tsubo/person, there will be an improvement of productivity of 775,500 JPY/tsubo per year [149].

This was equivalent to more than 5 to 6 times the annual energy cost of general office buildings [77].

The total investment amount required to improve productivity was 108,900 JPY/tsubo.

$$\text{Productivity Evaluation Index} = \frac{775,500 \text{ JPY/tsubo}}{108,900 \text{ JPY/tsubo}} \times 0.10 = 0.71$$

It can be understood that 0.71 times of the investment amount has been collected per year, and the reciprocal of this value was 1.4 years, which was a simple amortization of the total investment, which can be a very effective investment [149].

NISSAN OFFICE HEADQUARTERS, YOKOHAMA.

The light and thermal environment were measured and verified the energy saving impact, through an experiment carried out by Nissan Motor Corporation in collaboration with Professor Ikaga Laboratory in 2013 [99].

Also, comfort, satisfaction, impact on work efficiency and power consumption assessment were computed, when the operation improved, due to the change settings for light and thermal environment.

As a result, minus 59 kg-CO₂ / sqm per year was achieved in the first year, reducing 24% of kg-CO₂ / sqm emissions comparing with the old building. The second year, about 35% was reduced while maintaining comfort.

Figure 28 and 29 show the average values of the responses of all areas of the satisfaction level and intelligent productivity on the indoor environment and power saving at the regular office time before relocation and at the new building.

Regarding the satisfaction with environmental light, it was somewhat dissatisfied as the result of the relocation. It was considered that the primary cause is the turning off general lighting in the office area due to power saving measures summer of 2011.

However, more than 40% of the workers answered satisfactorily, and the effect of natural lighting from the window surface was reflected.

Figure 28. Satisfaction with the environment. Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."

Figure 29. Subjective evaluation on intellectual productivity (office area). Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."

Regarding satisfaction of temperature, air, sound, space environment and overall environment other than the light background, it was a satisfactory result than office before relocation.

Also, it was shown that subjective assessment on intellectual productivity such as ease of concentration, ease of communication, individual work efficiency was maintained or improved.

Regarding economic evaluation, targeting the company's goals, four intermediate indicators on intellectual productivity were transferred from standard level 3 to excellent level 5 into CASBEE evaluation.

This section shows the effect given, the additional rent rate [%] for relocation to the new building, and the contribution ratio.

According to Murakami's formula, it is possible to estimate the economic value of the intellectual productivity improvement. Hence by applying Equation 1 in this case study we can obtain this value as follows:

$$\begin{aligned} \text{Economic value} &= 70.3 \times (\text{work efficiency Index} - 100) + 111 \times (\text{knowledge} \\ &\text{creation Index} - 100) + 118 \times \text{employee motivation Index} + 70.3 \times \text{securing} \\ &\text{personnel Index} = 2,213 \text{ (JPY/month} \times \text{tsubo)} \end{aligned}$$

Table VIII shows the intermediate index improvement amount by devising these various building spaces and indoor environmental facilities. The amount of increase is higher for each intermediate index, and Figure 30 illustrates the comparison with the results of the old head office evaluation before relocation.

Finally, Table VIII represents the results of the assessment of the global headquarters.

Figure 30. Comparison of assessment results between the old building and new building. Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."

Table VIII Item and level of intellectual productivity evaluation system. Source:
Self-made based on "The 10th International Conference on EcoBalance
(EcoBalance 2012)-Challenges and Solutions for Sustainable Society."

Evaluation item	Weighting factor of intermediate index			
	Work efficiency	Knowledge creation	Employee motivation	Securing personnel
Thermal environment	1.76	-	-	-
Air ring	0.21	-	-	-
Extensive office space	1.37	0.71	1.72	1.48
Ceiling of office space	0.97	0.51	0.48	0.45
Daylight in office space	1.36	0.73	1.02	0.75
Natural ventilation of office space	1.15	0.64	0.66	0.36
Having outdoor information in the office space	1.13	0.64	0.49	0.3
Consideration for interior	1.17	0.66	0.7	0.96
Maintenance and hygiene pipe	1.28	0.7	1.11	0.96
Meeting space*	-	0.77	0.9	1.09
Refresh space	-	0.75	1.09	0.88
Dining hall / cafe*	-	0.67	0.76	0.98
Devices of moving space*	-	0.6	0.29	0.54
Entrance lobby*	-	0.53	0.18	0.46
Green spaces	-	0.63	0.25	0.18
biodiversity	-	0.58	0.09	0.07
appearance	-	0.4	0.17	0.42
Regional Contribution	-	0.47	0.1	0.13

*Satisfaction level of office worker (5 grades evaluation) Use result of questionnaire

Table IX Intellectual productivity evaluation result and economic value (additional rent). Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."

Evaluation item		Evaluation results	
		Old building	New building
Intermediate index	Work efficiency Index (%)	0.9	6.5
	Knowledge creation Index (%)	0.8	5.4
	Employee motivation Index (%)	0.8	6.3
	Securing personnel Index (%)	0.8	5.9
Economic value (JPY/month x tsubo)		296	2,213

From the results obtained by Kajima Corporation, Shimizu Corporation, Nikken Sekkei Ltd. and Nissan Motors, we can establish the discussion that is exposed below.

Table X. Comparison of results between Case Studies.

	Kajima Corporation Technical Research Institute (KaTRI), Tokyo	Shimizu Corporation Office Headquarters, Tokyo	Nikken Sekkei Ltd. Office Headquarters, Tokyo	Nissan Office Headquarters, Yokohama
Architectural variables in the experiment.	Thermal, light, sound environment	Thermal, light environment	Thermal, air quality, sound environment	Thermal, light, air quality environment and the impact of the refresh area
Satisfaction improvement.	9.38%	47%	0	12.5%
Productivity improvement perception.	80%	43%	4.7%	2.5%
Economic value of the productivity improvement	-	-	(+) 1,969.8 €/sqm (per year)	(+) 734.52 €/sqm (per year)

The design strategies followed to conceive a Green Office Building represent a direct benefit in the people's satisfaction and productivity and are demonstrated through the application of methodology shown in the Case Studies.

Likewise, it is shown that even small investments have a high return regarding economic value for the Company.

Nikken Sekkei Ltd. Office Headquarters, where with a reduced investment of 278 €/sqm, 1,301.95 €/sqm lower than the average price of the square meter built in Tokyo [104], and with a moderate increase in productivity of 4.7 %, a return on investment is achieved in the short term 1.4 years, from which it begins to obtain net profit.

Nissan Office Headquarters, where the intellectual productivity improvement had the economic value of 61.21 (€/month x sqm). This means about 17.7% over the average recruitment rent in the same type of buildings in the same area.

There are notable differences among the satisfaction values achieved in the four case studies after applying the methodology shown. However, the architectural variables studied are redundant. This is due to external factors that affect results and should be included and clearly documented as lessons learned, to be taken into account of future projects approach.

These factors are mainly the psychological factor of the people participated in the experiment, and global external factors, such as the economic, political and social conjuncture.

As an example, in Table XI we could point out the Nissan Office Headquarters Case. The construction in 2011 of this building coincides with a major environmental disaster in Japan, which forced to apply restrictions on electricity supply, which affect in satisfaction reflected in the experiment.

From the results discussion, it emerges two key factors directly affect the magnitude of the impact on the Triple Bottom Line, and within it in productivity, of Green Office Building design strategies.

On the one hand, the selection of a set of strategies optimized to the needs and circumstances of each company, and these reflected in its corporate building. This optimal strategy set should be carried out promptly according to strategic business interests.

5.4. Conclusions.

An optimized strategy to increase productivity has a direct impact on the Triple Bottom Line approach.

Productivity improvement is associated with an impact on environmental aspects (many sustainable operational strategies are de facto "Planet" triple bottom line strategy), is affecting the intrinsic value of the asset (Profit) and improves the satisfaction, comfort, health and wellbeing of the users (People).

According to the Case Studies, the architectural variables that have the greatest impact on increasing productivity are the thermal environment, light environment, noise absorption environment, and air quality. Also have a significative impact office openness, atmosphere, amenity and individual level controllability.

As the best of our knowledge, these variables are the most studied in the State of the Art, thereby we consider that it would be proper analyze new variables related to the new office environments.

The great dispersion of the results obtained is due to conjunctural external factors, of economic, social and political scale, that affect the subjective perception of the personnel, and that must be considered in the analysis of the data.

The methodology utilized is demonstrated as an effective method of quantification of increase in productivity. However, we consider that it would be necessary to correct the experiment development schedule to avoid the so-called "end effect" [35] in the Task Sets.

The analysis and discussion of the Scenario studies demonstrate the real need to go deeper into the subject, since there is a lack of relevance in most of the research about the workspace as a business engine, while the Scenario studies reveal that the investment in the design of these spaces is profitable.

Productivity must always recognize that there are many truncated aspects to evaluate the outcome of intellectual labor which is difficult to evaluate only from the economic side and make a final assessment.

Productivity evaluation is realized by integrating various disciplines. Therefore, cooperation in different fields such as economics, statistics, sociology, psychology, physiology, as well as architecture are necessary.

Companies are shifting their focus, from valuing tangible assets to giving more importance to intangibles, such as research and development, marketing, human resources management, innovation management, and branding.

That has an implication in the way the workspaces are developed, designed and managed, and supports that support transfer and connection are needed.

In Japan, exists an extensive literature on quantification of productivity studies in workspaces and their impact on Sustainable Facility Management and the value of real estate assets. However, the clear majority is published in the Japanese language.

6. ANÁLISIS CUALITATIVO DE CASOS DE ESTUDIO. AUSTRALIA

6.1. Green office building activity and trends in Australia.

Australia is a relatively mature green building market, with stable growth and a clear commitment to green building.

An increased focus on health and concern about the perception that green building is for high-end projects only are the key factors that differentiate Australia from other global markets [121].

According to a study conducted by Green Building Council of Australia, there are strong business benefits driving green [121].

They are roughly consistent with the global medians, although they are more optimistic about one-year operational cost savings in new buildings and five-year operational cost savings in retrofits than the global medians [56].

Table XI. Expected business benefits of Green Building in Australia. Source: Green Building Council of Australia.

	NEW Green Building		Green Building REFORM	
	2012	2015	2012	2015
Decreased operating cost over one year	8%	11%	8%	7%
Decreased operating cost over five years	14%	13%	14%	13%
Payback time for green investments (years)	9	8	7	9

6.2. Energy rating tools in Australia.

NABERS.

NABERS ratings measure and rate the energy and other resource consumption of a building, based on actual collected data. There are a range of NABERS office rating tools, which measure variously energy, water, waste and indoor environment [102].

NABERS is a rating scheme for existing buildings. Performance is measured by analysing the annual use of resources.

The aim of NABERS is to encourage innovation and market best practice to achieve positive environmental outcomes, including lower greenhouse gas emissions, reduced water consumption, less waste and healthier working environments.

GREEN STAR.

Green Star is a voluntary environmental rating scheme that evaluates the environmental design and construction of buildings. Ratings are available as “design” (for a limited period only) and “as-built”.

The Green Star system assesses the environmental design and construction of buildings by considering their management, indoor environmental quality, energy use, transport proximity, water and materials use, land use and ecology, emissions, and innovative features.

Green Star was developed for the property industry to establish a common language of green building attributes, set a standard of measurement for green buildings, promote integrated, whole-building design, recognise environmental leadership, identify building life-cycle impacts, and raise awareness of green building benefits.

The Green Star system is administered by the Green Building Council of Australia, which is a national not-for-profit organisation with the mandate of developing a sustainable property industry in Australia and driving the adoption of green building practices.

6.3. Retrofitting Australian initiatives.

RETROFITTING MELBOURNE. 1200 BUILDINGS SCHEME.

The City of Melbourne 1200 Buildings Scheme is aimed at reducing energy emissions and water use from commercial buildings, including office buildings.

Due to an amendment in Victorian Legislation, financial institutions will be able to advance funds to commercial building owners for environmental retrofitting works to combat the issue of obtaining finance for environmental upgrades.

Some of the aspects of the 1200 Buildings Scheme may make it difficult for lower grade building to apply. Firstly, as the 1200 Building program is only eligible for buildings located within the boundaries of the City of Melbourne, a large portion of the low-grade building market in Victoria will not be eligible.

The unintentional impact of legislation, which currently precludes building owners from securing debt in cross collateralised portfolios, is a disincentive for building owners of low grade buildings who often experience capital constraints. Also, the 1200 Buildings Program is not eligible for buildings that are owned by trusts which limit the number of buildings eligible for funding.

Although there is no information available regarding the number of low grade buildings owned by trusts, since they comprise of a large percentage of the total office market it is recommended that more detailed information should be captured about ownership types across Victoria.

GREEN LEASE.

A Green Lease provides a framework under which both landlord and tenant can achieve and maintain energy efficiency and other sustainability goals throughout the lease term. Furthermore, it enables better environmental and economic performance of a building.

A Green Lease can include information about:

- What are the environmental measures to be taken under the lease?
- How will the parties cooperate to achieve these measures?
- Who will monitor compliance with those measures?
- What happens if the targets are not met?

There is no uniform model Green Lease that will be appropriate for every commercial premise. Like an ordinary lease, there is no one-size-fits-all model. However, components of a Green Lease can be mixed and matched to suit the objectives and requirements of the parties [121].

A Green Lease can provide tools for the better management and operation of buildings, including the collection and sharing of sustainability information, adoption of targets, management plans and mechanisms to facilitate building upgrades.

ENERGY EFFICIENT OFFICE BUILDINGS REFORM.

An energy efficient office building is one that is saving energy, has reduced bills and happy, comfortable tenants.

In Australia, energy consumption of office buildings is approximately 25% of all energy consumption, which represents a significant proportion of total greenhouse emissions. Improving the energy efficiency of office buildings can result in energy savings of more than 50 percent [40] – with some buildings capable of producing more energy than they use.

Figure 31. Distribution of energy consumption in office buildings in Australia.

Source: The Green Lease Handbook. Council of Australian Governments. 2012.

Cost-effective energy efficiency improvements can significantly cut costs for owners and tenants – simple measures can result in approximately \$10,000 per annum savings for an average office space of 2,500 m². An energy efficient office building may also mean:

- Lower maintenance bills.
- Happy, comfortable tenants.
- Reduced energy use and a reduction in costs for owner and tenants.
- Increased asset value.

- Deferred capital costs and lower maintenance costs (well-tuned equipment lasts longer and breaks down less often).
- Increased appeal to tenants and longer lease times.
- Future proofing building assets against rising energy costs and regulations.
- Reduced greenhouse gas emissions.

In general, most used measures to reform office buildings in Australia are:

- Using passive measures like shading, insulation and double glazing to reduce the need for air conditioning.
- Invest in an efficient, appropriately sized HVAC systems that are well commissioned, maintained, and tuned – HVAC accounts for up most of energy costs in a commercial building, and an energy efficient HVAC system can save up to 40 percent of these [6].
- Install an energy efficient, controllable lighting system that maximises the use of natural light. Less than 7 watts per square meter is considered best practice. Moving to a sustainable lighting system can save you as much as 80% less energy in some Scenarios.
- Ensure your Building Management System (BMS) allows for fine control of lighting, heating and cooling systems.
- Use renewable power sources either on site (Solar PV or Solar Hot Water) or off site through the purchase of accredited Green Power.
- Install lifts that are programmed to prioritise the most energy efficient option and capture energy from their brakes.
- Use benchmarking tools such as NABERS or Green Star to compare your building to other efficient buildings and identify areas for improvements.

WORKPLACE PRODUCTIVITY AND HEALTH.

From a business perspective, there are clear incentives for improving employee health and productivity. Research shows that the green design attributes of buildings and indoor environments can improve worker productivity and occupant health and well-being, resulting in bottom line benefits for businesses.

Despite evidence of its impact, improved indoor environmental quality has not been a priority in building design and construction, and resistance remains to incorporating it into financial decision making.

This lack of uptake is likely because “productivity” in the modern workplace can be challenging to measure, its causes woven with several factors, and it has been systematically translated into financial metrics. While more research is needed, investing in better indoor environments can lead to better returns on one of every company’s greatest assets: its employees.

Over 85% of total workplace costs are spent on salaries and benefits, compared to less than 10% on rent and less than 1% on energy. Research suggests that by making even small improvements to factors such as productivity, health and well-being, businesses can experience greater financial benefit than they would from more efficient resource use in buildings operations.

It is not surprising that the business community is increasingly interested in how green building design can positively impact its people. Some leading businesses are now shifting their thinking from “how much will green building cost my business” to “how much will not investing in green building cost my business?”

While businesses are increasingly recognizing that buildings that better support their employees also result in better organizational outcomes, they are less certain of how they should be leveraging buildings to positively impact people.

In addition, many businesses believe that people can adjust to any environment and so often make changes to the environment only when it directly interferes with work performance, rather than being proactive and exploring how the environment can positively influence productivity and well-being.

Table XII. Net present value of the operational cost and productivity and health benefits of LEED certified buildings. Source: *The Business Scenario for Green Building*. World Green Building Council. 2013.

OUTSIDE VIEWS	Mental Function and Memory 10-25% BETTER.	Call Processing 6-12% FASTER.	Hospital Stays 8,5% SHORTER.
DAYLIGHT	Students achieve 5-14% HIGHER TEST SCORES and learn 20-26% FASTER.	Workers are 18% MORE PRODUCTIVE.	15-40% INCREASE in Retail Sales.
SYSTEMS	Productivity increases by 23% from better lighting.	11% from better ventilation.	3% from individual temperature control.

6.4. The link between green buildings and workplace productivity.

THE IMPACT OF DESIGN.

Attributes of green buildings most commonly associated with healthy indoor environments include high levels of natural daylighting, appropriate levels and types of artificial light, use of materials with minimal toxins, appropriate outdoor air ventilation, thermal comfort and open and inviting spaces that increases interaction and physical movement.

One of the challenges of research in this area is that there are several physical environment factors that may be simultaneously impacting productivity, health and well-being, and these contributing elements may also be acting synergistically, creating impacts that are not well understood or even known [70].

However, many studies have been able to isolate specific attributes and their impacts. For example, in a well-regarded study from 2009 performed by Dr Mardaljevic, performance of office workers was assessed under differing amounts of access to daylight and to views of nature.

Workers with outdoor views to vegetation through windows processed calls 6% to 12% faster and performed 10% to 25% better on mental function and memory tests than workers without views [27].

The Centre for Building Performance and Diagnostics (CBPD) along with Advanced Building Systems Integration Consortium (ABSIC) at Carnegie Mellon University reviewed and assessed the existing research on building design attributes and workplace productivity [97].

They found:

- 8 Scenario studies linking the benefits of providing individual temperature control for each worker to measured productivity gains, demonstrating up to a 3% increase in overall productivity.
- 15 studies linking improved ventilation with up to 11% gains in productivity, because of increased outside air rates, dedicated delivery of fresh air to the workstation, and reduced levels of pollutants.
- 12 studies linking improved lighting design with up to a 23% gain in productivity related to light levels matched to task, glare and brightness control, and the power of views.
- 13 studies linking the access to the natural environment through daylight and operable windows to individual (up to an 18% increase) and organizational productivity (such as increased retail sales).

Occupants of other buildings types have been shown to benefit from these same design features. For instance, in the Economics of Biophilia, the authors highlight several reports showing the benefits of views to the outdoors and daylighting across several sectors [158]:

- The seminal study by Ulrich, 1984, showing hospital stays reduced by 8.5% as well as supporting studies indicating faster recovery rates in rooms with windows views of nature [159].
- Patients with a 22% reduced need for pain medication in rooms with bright sunlight [159].
- Significantly increased sales per square foot in Walmart, a 15-20% increase in sales at Target, and 73-store retail chain in California with 40% increase in sales due to daylighting [159].

While these green design features have proven benefits, they must be incorporated into a holistic design of the whole building, or they may have unwanted results.

The most obvious example is daylighting, which must be incorporated into the design correctly to minimize glare and eliminate unwanted heat, both of which can have a negative impact on productivity.

MAKING THE MOST OF GREEN BUILDING DESIGN.

The importance of building design in achieving individual health and well-being as well as individual productivity is a prominent agenda item for the building industry.

While there is a growing body of research and empirical evidence linking building design attributes to productivity, health, and well-being, the results of this body of research has not been well integrated into building design and there has not been a consistent method to link the outcomes to financial metrics.

As result, while the evidence is there, the industry remains sceptical and continues to under-invest in the occupant experience, missing out on what is potentially its greatest return on investment.

The implications reach beyond individual businesses. A recent study from an Australian university asserts that workplace productivity and human performance are major determining factors in overall national productivity and outputs, influencing national growth rates and quality of life [41].

There is a significant opportunity for business and academia to work more closely to build the evidence for the links between green building design and organizational success, drawing on the wealth of information we already have about its impact on individuals.

We need an integrated approach that connects the existing research data to practical applications, financial returns and, ultimately, policies and standards.

A greater evidence base will be crucial to moving our investments in the built environment away from minimizing cost to maximizing employee health and productivity. In doing so, employers should view their physical environments as tools to leverage broader organizational success and unlock significant value.

Building investors and owners should recognize and act on the information already available with the understanding that design decisions made now will have an impact on workers over the life of the building and therefore the long-term value of their investment.

TALENT ATTRACTION AND RETENTION IN GREEN BUILDINGS.

Green buildings, particularly those with improved indoor environmental quality, are being shown to positively impact human health and performance. But can green buildings also improve a company's ability to attract and retain key staff? The experience of those occupying green space seems to affirm this link, and progressive human resource professionals are taking note [30].

The Importance of Staff Attraction and Retention.

Employee turnover is costly to any company, but especially in knowledge fields where the competitive edge is human expertise. But turnover is not an adequate term to describe the real costs of losing an employee.

These costs include the cost of termination, job postings, interviews, negotiations, lost productivity due to job vacancy, and the learning curve productivity loss [46].

Attraction-retention may be a more powerful way to capture these comprehensive costs rather than the somewhat benign use of the word turnover.

In his paper, *It's Costly to Lose Good Employees*, Dr Jac Fitz-Enz, an expert in human capital strategic analysis, indicates that when direct and indirect costs are combined, the total turnover cost of a professional or manager is a minimum of one year's pay and benefits and can be as much as two years' pay and benefits.

For this reason and more, Dr Fitz-Enz believes that "the primary human resources challenge... is the recruitment and retention of competent employees." Indeed, employee retention is considered one of the key indicators of "overall organizational success".

A 2009 CBRE report found that "public image, recruitment of and retention of employees are enhanced in green buildings". So, it follows that green buildings could result in significant savings in the costly arena of employee turnover.

The evidence bases.

The Colliers International 2012 Office Tenant Survey assessed 300 decision-makers leasing commercial property, representing 5.5% of Australia's total office space. In the two years since the previous survey, key priorities of tenants had shifted from a focus on business expansion to staff attraction and retention.

Simon Hunt, Colliers International Managing Director of Office Leasing, linked attraction-retention with the greenness of the workplace, saying that workers "...want to be able to say they work in a 'green' building." In fact, 95% of tenants said they wanted to occupy a 'green' building, up from 75% in 2010.

A 2008 study by Deloitte and Charles Lockwood examined the motives for companies choosing green retrofits over conventional retrofits. "'Corporate environmental commitment' topped the list of motives for the green retrofit, and more than half the respondents also identified greater indoor air and environmental quality, public relations and publicity, improved employee productivity, and enhanced employee attraction and retention as important drivers," the report found.

Following the green retrofits, 93% of the respondents reported greater ability to attract talent and 81% saw greater employee retention.

These examples all show that building design that contributes positively to human well-being and performance is increasingly forming part of a company's strategy to attract and retain workers.

In addition, the building itself may act as a symbol of the corporation's environmental and social performance and be a powerful attraction for potential employees.

NEXT STEPS.

After performing the analysis of the State of the Art concerning the relationship between productivity-wellbeing and workplace, the following questions arise:

- Which green building features or combinations of features have the greatest impact on human health and productivity and organizational success? How do these vary by building type?
- Can an existing building evaluation system or framework measure and then calculate the cost-benefit of these new strategies?
- Can a building owner or business leverage their healthy and productive building /space to obtain improved financing or health insurance rates?
- How can we best turn the results of productivity measures into meaningful financial metrics?

6.5. Risk mitigation.

Investor risk relates to the potential reduction in value or increase in costs associated with holding an investment.

It may also relate to the brand strength of an investor and therefore the ability to attract equity and debt competitively.

- Sustainability risk factors can significantly affect the rental income and the future value of real estate assets, in turn affecting their return on investment.
- Regulatory risks related to sustainability have become increasingly evident in countries and cities around the world, including mandatory disclosure, building codes and laws banning inefficient buildings.
- Extreme weather events and systematic changes in weather patterns affect the insurability of real estate and lead to questions about the resilience of assets.
- Changing tenant preferences and investor risk screening may translate into risk of obsolescence for inefficient buildings.
- Sustainability represents an assortment of risks and possible rewards for real estate investors.

There are different risks evaluated at the various stages of the building life cycle, but all can be considered ways in which to "future-proof" investments.

While there are few evidence-based studies quantifying sustainability-related risks, some real estate investors are now performing their own analyses on many of these risks as a part of their decision-making processes.

Real estate investors have responsibilities to their shareholders and other beneficiaries to ensure that profits, which flow because of income produced in rent and increasing capital values of real estate assets, are achieved over short- and long-term horizons.

The beneficiaries of investor's activities include shareholders in private companies, insurance and pension policy holders, private individuals and public bodies. Many of those whom we identify as "real estate investors" are merely fiduciaries of other people's money, which has been entrusted to their care in the expectation that they will enable that money to grow in value, while minimizing the risk of the investment.

Dealing with sustainability issues is therefore no different to dealing with other risks; investment decisions are made based on downside and upside risks, including those presented by sustainability.

Below I identify some of the most pertinent sustainability issues, why they represent risks and how some investors are currently dealing with them.

REGULATORY RISK.

Any market exists within a political and regulatory context and investors are obviously used to operating within those boundaries. As real estate investment management is a relatively long-term play, investors need to appreciate how future legislation can impact the value of a building and its cash flows.

Regulation of sustainability issues, like carbon emissions, has become increasingly important real estate investors because the built environment is regarded as "responsible" for significant environment impact, leading to climate change.

In many countries, building regulations and codes tend to focus on new buildings and seek to ensure that their sustainability performance is far better than much of the existing stock. Investors' portfolios will rarely consist of a large proportion of new buildings, meaning they need to ensure that their existing assets are able to compete against new buildings for occupiers and purchasers.

In doing this, they will try to ensure that they future-proof their assets against evolving regulations which tend to require ever better sustainability performance.

Regulatory risk does not only include the performance of a building itself, but of its location as well. Although planning regulations covering urban transport and increased density requirements are now prevalent in some countries, it is possible that in the future these requirements will be widespread and change the importance of accessibility for both tenants and building owners. Investors have traditionally placed the highest value on location factors and will have to reassess the sustainability risk factors pertaining to some building locations.

There is increased consensus that governments will implement regulations that target sustainability factors far more aggressively than has previously been the Scenario, and investors will need to understand what the consequences will be.

They will need to consider how the building performs in terms of its own sustainability profile - where risks might arise because of its perceived ability to be efficient in the consumption of resources compared to other buildings' compliance with regulatory requirements.

If investors' buildings fail to meet the changing requirements of regulations, or seem to perform less favourably when compared to other buildings, then they will suffer from increased risk of obsolescence.

MARKET RISK.

As well as responding to regulatory pressure, real estate investors simultaneously need to understand how sustainability affects them from a market perspective – in terms of supply, demand and associated factors. Investors will consider factors relating to asset-specific risks and risks affecting the performance on their portfolios, like their ability to raise capital.

Occupancy risk: The financial performance and valuation of real estate asset is to a large part determined by the security of its cash flow. The likelihood that tenants might leave a building or not lease in the first place, because of its inadequate sustainability performance is recognized as a key risk by investors.

Evidence for preference amongst occupiers for green buildings can be found in several surveys in which the cited drivers relate to factors such as: proximity to public transportation; cheaper running costs and utility bills being reflected in lower service charge costs; better productivity; human resource factors like recruiting the best talent; and public association with sustainability.

Many researchers and market practitioners believe that there is a strong correlation between those buildings that retain their value because they are “prime” buildings and those described as “green”.

The question that therefore becomes more and more important is: will an asset will suffer from a “brown discount”, or increased obsolescence because is not green? Considering this, investors need to identify the potential impact that a purchase or disposal might have on the risk profile of their portfolios.

Overall, studies have demonstrated that greener portfolios have better operating performance and are exposed to less market risk. However, most property investors are not convinced of the shareholder value potential associated with energy efficiency or other environmental investments.

This could be because real estate investors do not sufficiently and clearly report their sustainability performance and the risk reduction this affords [38].

In 2012, a study has indicated that the financial performance (stock price) of REITs with a higher percentage of certified buildings (Energy Star and LEED) shows lower risk exposure (less volatility) than those with a lower percentage of certified buildings. This mirrors the effect that high carbon emissions have on firm value in other industries [39].

In the context of real estate investment, identifying the value impact of sustainability is, of course, vital and this must be measured over time rather than as a snapshot.

To explore whether more environmentally efficient real estate portfolios may be able to outperform their peers in terms of risk and return, several “green property” indices have been developed.

In all business sectors, there are potential risks to a company's brand and performance arising from the activities and associations of its investment partners. A study by Bauer and Hahn in 2011 confirms that companies with better environmental performance exhibit cheaper debt financing costs, supporting the contention that firms with more socially responsible practices have higher valuation and lower risk.

The impact of real estate investor's asset and portfolio – level sustainability performance – and their management of the associated risks – can be felt in their ability to attract equity and debt at competitive rates. It is for this reason that an increasing number of real estate fund managers and their investors subject their portfolios to sustainability benchmarking.

Although there is limited evidence of investors deciding not to invest in funds based on sustainability criteria alone, some investors are including sustainability performance to identify "best in class" opportunities.

PHYSICAL RISK.

Climate change predictions represent a real risk for investors. The scientific consensus on future temperature increases indicates that changes to weather patterns will be significant in terms of the built environment's capability to cope with them.

Notwithstanding any societal adjustments that climate change may bring, real estate investment decision-making will have to evolve to reflect changes in the economic viability of different locations and the ability of different building types and designs to stand up to a changing environment.

A useful risk management context within which to consider this is in terms of resilience and the extent to which investments are future-proofed. As experienced recently in New York, Australia, Europe and in many other places around the world, there are many physical risks that are associated with climate change.

Investors will increasingly need to factor the ability of buildings to withstand predicted impacts into their decision-making. Perhaps chief amongst these impacts will be extreme weather events, flooding, subsidence and the ability of building skin and systems to cope with increased ambient temperatures and changing rainfall patterns.

For investors, one of the key risks they face in this regard is the insurability of buildings – **without this, a building's value could substantially reduce**, even to nil. Some insurers have taken the view that in certain locations, such as Australia, it is no longer economically viable to provide flood protection cover against risks to buildings and the businesses that operate from these buildings.

Given that insurer and reinsurers are likely to extend their thinking in this manner as extreme weather events and subsequent insurance claims become more commonplace, investors will need to start considering the risks to their assets' cash-flows if they have not already done so.

Investors will also have to consider the issue of building comfort and the ability of buildings' systems to ensure that occupiers will view premises as desirable; with increased temperatures predicted there is a cash-flow risk for buildings which are not sufficiently resilient to ensure future occupier satisfaction.

How investors deal with these issues will of course vary from place-to-place and building-to-building but it is inconceivable that efficient investors are not undertaking sustainability risk profiling of their portfolios.

In some instances, real estate owners will be able to mitigate these physical risks by sharing them, or their costs, with their tenants, but to do so they will need to ensure that leases make suitable provision for this.

Other mitigating measures will include retrofitting buildings with adaptations to deal with climate change effects, such as solar shading, improved drainage and water harvesting. Investors will also need to look at the resilience of local infrastructure, as even a resilient building will be compromised if it is in a city that has done little to manage physical risks.

TECHNOLOGY RISK.

Innovative technologies in new building have their own risks (e.g. LED lighting, HVAC equipment, solar systems) arising from unintended outcomes from their use - or the fear of these- or concerns about appropriate maintenance regimes. These can be barriers to implementing sustainability solutions.

However, reticence to use new technologies that can change demand-side behaviour could increase the risk of obsolescence and missed opportunities for reduced operational costs.

Sustainability represents several risks and potential rewards for real estate investors. To mitigate the former and benefit from the latter, investors need to understand the full range of sustainability issues that will affect their assets.

Figure 32. Risk radar. Source: *The Business Scenario for Green Building*. World Green Building Council. 2013.

6.6. Case studies.

CASE STUDY. GPT GROUP, SYDNEY.

When Australian property company The GPT Group (GPT) made the decision to upgrade its head office space in Sydney's central business district, the conversation quickly turned to how a green refurbishment could help transform the Group's operating model and reinvigorate the GPT brand.

As the company would soon discover, the upgrade, which has achieved the highest available rating under Australia's Green Star rating system, would transform the working environment and improve conditions for GPT Group employees.

The new office has become a symbol of the organization's approach to business and has delivered a significant boost to GPT's brand. Since the achievement of its green building certification, GPT has been recognized with accolades for the office and business alike, including three state government Green Globe Awards.

GPT has also been named the world's most sustainable real estate company for 2012/13 by the Dow Jones Sustainability Index.

The efficient use of sustainable materials was a core tenet of the GPT fit out design brief. Adhering to the philosophy of 'everything old is new again', the project team repurposed and reintegrated many items from the old fit out into the new space and achieved an incredible 96% waste diversion rate.

The GPT Group also entered into product stewardship agreements with all suppliers, ensuring that fit out items have a low environmental impact – now, and at the end of their useful life.

To boost the air change and energy efficiency of the base building's dual active chilled beam and variable air volume systems, the project team introduced supplementary air conditioning for meeting rooms and installed louvers within the façade to increase the levels of fresh outside air.

Optimizing air conditioning efficiency has helped to achieve significant reductions in energy use across the tenancy and air change efficiency is now 50% higher than Australian standard requirements.

The significant boost to indoor environment quality was also achieved through the specification of furniture, carpets and soft furnishings that were low in volatile organic compounds (VOCs) and the introduction of more than 500 plants to further improve air quality for GPT workers.

Because of these efforts, the latest post-occupancy study indicates a massive jump in GPT employees' comfort and satisfaction in their new workplace.

Prior to the move, GPT workers rated their overall comfort with aspects of the space including temperature, ventilation and acoustics at 54%, while in the new space the overall comfort ratings have jumped up to 97%. Further, the first employee self-assessment post occupancy study for the office – conducted three months after the move – found that employees felt 15% more productive in the new space.

“I find the control I have over the environment as a user of the space is fabulous – being able to move around and chase the sunshine around the building, or adjust the lighting and air as I need it is great,” said one GPT worker.

Another GPT employee sums up the sense of pride the people at GPT feel for their new workplace. “I’m proud to say I work in a green environment,” the employee said. “Achieving the 6 Star Green Star rating was a wonderful acknowledgement of the importance we place on sustainability. I’ve never worked in an environment that feels this open, fresh and healthy, while also providing me with all the facilities I need to be productive and effective in my role.”

Figure 33. GPT Group Headquarters in Sydney. Interior view.

Figure 34. GPT Group Headquarters in Sydney. Stairs.

Figure 35. GPT Group Headquarters in Sydney. Workstations.

CASE STUDY. 388 GEORGE STREET, SYDNEY.

Table XIII. Main data of Case Study 388 George Street, Sydney.

OWNER	Brookfield and Investa
LOCATION	388 George Street, Sydney, NSW
SIZE	44.887 m2 gross floor area, refurbishment of existing 30-storey building constructed in 1976
COST	\$ 22 million
PROJECT MANAGER	Brookfield Multiplex Services
CONSULTANTS	AECOM, Viridis E3, Phoenix and Graypuksand

Main features:

- 4 Star Green Star refurbishment completed with tenant in-situ.
- Energy consumption reduced by 1,9 million kWh per year compared to the pre-refurbishment levels, equivalent to taking 257 cars off the road.
- Water demand reduced by 16%, saving 5,5 million litres of water per year.

Figure 36. IAG House Headquarters in Sydney. Facade.

Brookfield and Investa have transformed IAG House at 388 George Street, a 30-storey commercial office block constructed in 1976, from an energy-guzzling tower into a symbol of sustainability in the heart of Sydney.

In doing so, they have demonstrated that tackling the existing building challenge is not only feasible, but makes good business sense.

“Upgrading IAG House was important for Brookfield, as we are committed to the continuous improvement of energy performance in existing buildings just as much as new buildings”, says Kurt Wilkinson, Chief Operating Officer of Brookfield Office Properties Australia. “Our goal is to provide office space of the highest quality while reducing operating costs.”

The refurbishment illustrates Brookfield's commitment to finding innovative solutions to environmental and sustainability challenges. These include features such as a rooftop rainwater harvesting system which supplements the cooling towers; use of recycled and repurposed materials in the bathroom renovations; and installation of smart meters throughout the building, which deliver highly-detailed energy usage data.

Products and materials used included:

- Low Volatile Organic Compound (VOC) adhesives and sealants
- Low emission formaldehyde to composite wood products
- All timber and composite timber products are FSC certified (Forest Stewardship Council)
- Dual flush toilets
- Sensor operated low flush urinals
- Tap ware mixers
- Cleaners taps with 6L/minute flow restrictors

- Replacement of energy inefficient hand dryers with paper towel dispensers
- Energy efficient lighting
- Metered soap dispenser system using vegetable based soaps

What makes this achievement more impressive is that there was a tenant requirement to remain in-situ, on every floor, during refurbishment works. The project team developed a raft of innovative and sustainable solutions to overcome this challenge.

Rather than replace existing systems, such as lift services and the HVAC system, the team reviewed each with the aim of maximising their operational and serviceable life. This reduced new material consumption and disposal of otherwise serviceable items.

Bathroom refurbishment works were undertaken in stages to accommodate the tenants' operational needs and avoid down-time. Materials such as partitions were re-used to avoid material wastage and increased resource use, minimising unnecessary additions to landfill. A new dual flush system was installed on all existing toilets to reduce the demand on the municipal water supply.

Detailed coordination and cooperation between tenants and Brookfield's management team ensured that the potentially complex upgrade of a fully-occupied building was executed with minimal disruption to tenants, neighbours or the environment.

"Our experience in collaborating with the tenant and building management teams to ensure after-hours works were carried out seamlessly demonstrates that sustainable retrofits can be undertaken even while fully tenanted", Kurt Wilkinson concludes.

Table XIV. Goals achieved in Case Study 388 George Street, Sydney.

MANAGEMENT	The building will undergo commissioning and building tuning at least every quarter during the first year of operation. This process will ensure that the building maintains optimum energy efficiency and that all systems work to the intent of design. On the lower ground floor, 55 m ² of dedicated recycling floor space has been provided to make it easier to recycle and therefore reduce total waste going to landfill.
ENERGY	Electrical sub-metering enables the facilities management team to monitor energy use, and identify and address any excessive use to save both energy and money. Upgrading the base building's lighting to energy-efficient globes resulted in a 10% saving on the total energy costs, when compared to pre-refurbishment. The total energy use of the building has been reduced by 1,9 million kWh per year, equivalent to taking 257 cars from the road for a year.
WATER	The refurbishment has reduced water consumption by 5,5 million litres per year. This was achieved by upgrading the building's bathrooms and installing WELS-rated fixture and fittings. A rainwater harvesting system has also been installed to supplement cooling tower water. This will reduce storm water runoff and lower demand for potable drinking water.

CASE STUDY. HUNTER STREET 39, SYDNEY.

Table XV. Main data of Case Study 39 Hunter Street, Sydney.

OWNER	Kador Group
LOCATION	39 Hunter Street, Sydney, NSW
SIZE	3.600 m2 total floor area
PROJECT MANAGER	JCK Consulting
ARCHITECT	Jackson Teece Architects
ENVIRONMENTAL CONSULTANT	Arup
STRUCTURAL ENGINEERING	Hyder
QUANTITY SURVEYORS	Davis Langdon
BCA CONSULTANT	Hendry Group

The Perpetual Building, 39 Hunter Street, Sydney, is the first heritage-listed building in Australia to achieve a 6 Star Green Star Office Design rating.

Increasingly, Australian existing buildings are being refurbished to meet the requirements of buildings owners and tenants for improved environmentally sustainable performance.

Older buildings need to upgrade and adapt to meet these changing needs and preferences if they are to compete with newer buildings.

About heritage buildings due to statutory constraints they can be a challenge to refurbish. Significant improvements can be made with minimal cost to any buildings through housekeeping review, energy purchase, improved maintenance and recommissioning of the building's services.

Challenges include the need to satisfy approval bodies that enough of the original fabric is being retained. The trade-off for loss of less significant fabric being the reinstatement of other concealed heritage features and the possibility of high environmental ratings.

Another significant challenge in upgrading the sustainability of heritage buildings is the dearth of building contractors with experience across both fields.

The building was built in 1916 and occupied by its former owners since then. It had undergone alterations in the 1960s and 1970s reflecting contemporary perceptions of “desirable” office space. The building is listed on the State Heritage Register and the Register of the National Trust in Australia, and is subject to a permanent Conservation Order.

Figure 39. 39 Hunter Street.

Figure 40. 39 Hunter Street. Facade.

Figure 41. 39 Hunter Street. Detail Facade.

At the time of purchase, behind the sandstone and trachyte façade (with slate and cooper mansard roof features) the retention of which scored high for both heritage approval and green ratings, little of historic value could be seen internally, with decorative cornices on the high plaster soffits covered by suspended ceilings.

Marble cladding to the main staircase and the panelled boardroom remained the dominant features of heritage interest. Natural light ingress to the lower floors was poor, resulting for partial infill of the two originals lightwells plus the overshadowing by more adjacent buildings.

The level of overshadowing became one of the most analysed aspects of the building. Arup engineers undertook numerous studies to determine the light penetration into the building both in its original form, following the partial infill of the lightwells, and via a proposed atrium in the optimum location to minimise intervention to the heritage structure while maximising light penetration to lower floors.

Infilling and existing void at the rear of the premises allowed this cutting through of a dramatic seven story atrium with minimal loss to the net lettable area of 6.300 m².

One of the most significant remaining heritage features, although damaged and cut during past “modernisation works”, were the beams and cornices of the original ceilings. To reinstate and retain these features, it was determined that a mechanical ventilation system that allowed the ceiling to remain exposed would be the best fit.

All alternatives were explored to meet NABERS targets along with obvious reticulation and plant constraints with the preferred technology being an underfloor displacement system. This was relatively innovative for use in a commercial building in Australia and met the objectives of indoor air quality, individual control, flexibility and reduced maintenance.

More importantly, using a raised floor plenum left the ceilings exposed and intact. Jackson Teece architects then developed a custom built “lily pad” to conceal services reticulation in the centre of each coffer of the undercrossing beams. This had the additional advantage of introducing a material to assist with acoustic control.

Other environmental features of the refurbished building include the use of gas fired generators used to run one of two chillers, as part of a peak load reduction strategy, and innovative use of an insulated sprinkler tank for pre-cooled water storage. Rain water will be collected and re-used to flush toilets. All storm water leaving the site is treated and filtered.

The refurbished building includes high efficiency luminaries, high frequency ballasts and energy efficient lighting controls. All timber and composite timber products used in the building and construction works were sourced from post-consumer re-used timber, or FSC certified timber. More than 95% of all painted surfaces, carpets and adhesives/sealants have been specified to comply with low VOC benchmarks.

The building will provide bicycle storage and showers for tenants and visitors, and dedicated waste management room.

A major intervention that almost caused controversy with the Heritage Office was the client's commitment to equitable access throughout the building. A wheelchair platform installed in the 1990s served the stepped entry from Hunter Street.

To enable ease of access for wheelchair users, the adopted scheme includes a 1:20 walkway (almost a ramp) from the street entry to the new lifts which provide access to all floors, including the raised tenancy area at ground floor level. Ultimately, the Heritage Office viewed this "intrusion" to the structure positively.

Securing approvals through Sydney City Council required a dedicated team effort, with JCK Consulting (Project Managers), Jackson Teece as Project and Heritage Architects working with Arup and Hyder Structural Engineers to determine the best solution for each issue.

The substantial intervention into the building was justified in part by the reinstatement of concealed remnant fabric, exposing ceilings and repairing cornices, maintaining evidence of strong rooms where these remain intact, keeping new plant levels back from the heritage façade and mansard roof structure and covering.

There was no doubt too that both the City council and Heritage office could see the value in the ESD strategies being employed.

Table XVI. Environmental initiatives in this project.

MANAGEMENT	Green Star Accredited Professional engaged from the commencement of the design phase. 12-month commissioning building tuning period including quarterly reviews and final recommissioning after 12 months of operation. Appointment of an Independent Commissioning Agent to ensure optimal building performance. Comprehensive Building Users Guide. Environmental Management Plan. Comprehensive waste management plan to divert 80% of construction waste from landfill. High levels of air change effectiveness and thermal comfort. Individual comfort control. Carbon dioxide monitoring and control. Thermal modelling to optimise comfort levels. Low-VOC paint, carpet, sealants and adhesives throughout the building.
ENERGY	Energy efficiency modelled to achieve an estimated 5 star ABGR rating. Tenancy sub-metering to enable effective energy monitoring. Low pressure drops displacement air conditioning system. Innovative use of the sprinkler tank as a cold store for base building electrical demand reduction. Gas generator coupled to chillers and pumps for base building electrical peak load lopping. Energy efficient T5/LED lighting. Variable speed pumping circuits for increase energy efficiency.
TRANSPORT	Secure bicycle storage facilities, lockers and change rooms.
WATER	Waterless urinals and 3/6 L dual flush toilets Water efficient fixtures Rainwater tank for recycling water and storm water retention.
MATERIALS	Shell and Core fitout to over 60% of the building. PVC minimisation. Re-use of façade and structure. Use of sustainable timber and re-use of existing timber. Recyclable carpet tiles. Use of <i>envirocrete</i> (recycled concrete) and recycled steel.
EMISSIONS	Low Ozone Depletion Potential (ODP) refrigerants. Refrigerant leak detection. On site storm water retention.
INNOVATION	More than 25% peak load reduction. Installation of "lily pad" ceiling system incorporating lighting and fire services.

Figure 42. 39 Hunter Street. Communication core.

Figure 43. 39 Hunter Street. Rooftop area.

Figure 44. 39 Hunter Street. Rooftop area.

Figure 45. 39 Hunter Street. Basement area.

Figure 46. 39 Hunter Street. Lobby.

CASE STUDY. 385 BOURKE STREET, MELBOURNE.

Table XVII. Main data of 385 Bourke Street, Melbourne.

BUILT	1983
NLA	Office 55.000 m ² Retail 6.000 m ²
TENANCY	Major Tenants include Commonwealth Bank, TRUenergy, UniSuper. The building also has approximately 50 retail stores and 2 levels of car park.
BUILDING OWNER	Commonwealth Property Office Fund.
PROPERTY MANAGER	Jones Lang LaSalle Management Services.
REFURBISHMENT PROJECT TIMELINES	2004-2011
PROJECT TEAM	Project Manager: Donald Cant Watt Corke. Facilities Manager : Jones Lang LaSalle. ESD consultant : Umow Lai. Contractors: AG Coombs, PARMAC and Johnson Controls.
PROJECT COSTS	\$2,5 million

The building, located on the busy corner of Elizabeth and Bourke streets, was completed in 1983 being a concrete and steel structure, with rectangular windows adorning a concrete façade.

The office podium is 45 storeys high, sitting at a 45-degree angle to the city grid. The building houses the Melbourne headquarters of the Commonwealth Bank and many the other commercial tenants, with a variety of retail stores and a large open food court on the lower levels.

In 2004, an Australian Building Greenhouse Rating (ABGR) rating (the predecessor to the National Australian Built Environment Rating System NABERS) was conducted on the building, which revealed a zero-star rating.

The consultancy Umow Lai then conducted a comprehensive environmental performance audit, which provided a list of options for the building to improve its energy efficiency.

As a few the mechanical systems of the building had reached the end of their life cycle, the recommendations were mainly directed at improvements to the efficiency of the heating, ventilation and cooling (HVAC) system.

The owners conducted a feasibility study to understand the risks and costs that would be encountered by the proposed system upgrades.

In 2005, the building owners agreed to go ahead with the works, and together with Sustainability Victoria and project managers Donald Cant Watt Corke produced a detailed project scope.

The project also involved a Umow Lai Environmentally Sustainable Design (ESD) consultant and contractors A.G. Coombs, PARMAC and Johnson Controls.

The main objectives of the first stage project was to lift the building from a zero NABERS Energy rating to a 2.5 rating – a target, which it was understood, was achievable. This objective was essential for the building to maintain relevance in the marketplace.

The plan included the upgrade and reinvigoration of the HVAC system in the building. This was conducted in two stages:

- Stage 1: This entailed refitting systems and rationalising previous upgrades, such as upgrading the building management system, rationalising building controls, introducing energy metering of the chilled water system, replacing fan motors, conducting active air quality measurements and reviewing after hours operation and zone control. A rational approach was adopted with planning, whereby the items recommended for upgrades or rationalisation were assessed within a set budget and understanding of ratings gains. This stage of the project has now been completed.
- Stage 2: This involves further upgrades mainly to HVAC reticulation such as heating and cooling water systems, chilled water controls and some additional sub-metering. The objective of Stage 2 is to further lift the NABERS ratings to at least a 3.5 Star NABERS energy rating.

The project was implemented over two and a half years and broken down into discrete packages, undertaken at the same time where practicable. For instance, changes to the boilers on level 43 and the chilled water system in the basement, which are essentially different systems, could be tackled at the same time. This improved the efficiency of implementation and reduced expenditure.

The building maintained near full occupancy during the upgrade.

Table XVIII. Architecture features of 385 Bourke Street, Melbourne.

BUILDING	There were no changes made to the structure or façade of the building. The building structure and skin were deemed to be in very good condition.
HVAC	Over time, as tenants moved and vacated floors, the building's HVAC had been retrofitted from a pneumatic to a Direct Digital Control. The legacy of this randomised refurbishment was that it left the building in an unbalanced state, and necessitated a complete recommissioning of the plant in line with the changes made to the new floors. This re-tuning or re-balancing was undertaken early in the project. Variable speed drives to fans were installed to each air-handling unit that serves a zone across a group of floors. This was a substantial investment involving eleven large air-handling units (AHU) with both supply and return air fan motors being retrofitted. The system was re-programmed to improve the use of economy mode (free cooling from cooler outside air when available) instead of using the chiller plant. This is considered one of the more significant energy-saving initiatives implemented in the refurbishment project. The air handling ducts to each floor were investigated systematically and any leaks sealed. The plant equipment was not changed, although the chiller's operation was revised in terms of stage up and stage down strategies, and a revision of cooling call logic. The installation of variable speed drives and the AHU logic change enabled the building to operate more efficiently in after-hours mode. Previously, half the building's HVAC plant would run to condition one floor and the fans would run at full speed across all floors. The distribution is now zoned at individual floors, which means that for afterhours use, there is greater control over each floor as well as the building. This has had a very positive impact on energy savings. Eight floors of the building had a different Building Automation System (BAS) to the rest of the building and this caused some control issues. Consequently, this was upgraded in line with the rest of the whole building, which enabled greater control over the central plant controls and consumption.

LIGHTING	Lux meter sensors are installed in the foyer and programmed to detect the level of ambient sunlight, which then determines the number of circuits that need to be switched on at any time. As floors are refurbished, the lighting is also significantly upgraded with energy efficient lamps, currently at T5s. Tenants then install smart controls including proximity sensors as the floors are partitioned.
WATER	Originally, domestic hot water was provided by the main boiler plant, which was oversized for this role resulting in significant energy losses. This system was replaced by six energy efficient quantum heat pump units; three located on level 42, and three on level 2. This has enabled the main boiler plant to be taken offline, except in seasons when building heating is required. Flow restrictors were placed on all taps in the washrooms, and showers received new water efficient heads. As floors are upgraded, the toilets are installed with the latest dual flush systems.
WASTE	In 2005, VISY was engaged to introduce one cardboard box for each workstation for recyclable waste (a co-mingled recycling program), and general waste confined to the kitchen area. All construction waste from floor refurbishments, plant and equipment, and other materials is recycled, achieving a 60 per cent recycling ratio. There is a cardboard baler to compress disused cardboard boxes. A centralised oil collection bin is available for the food court. A bin is provided for used lamps and tubes so that they can be disposed of correctly rather than sent to landfill.
ENVIRONMENT	Air handling systems actively measure, respond to and prevent CO₂ levels from rising too high. If required, more outside air is delivered to the office areas. Replacement of air curtains on entrances with automatic doors resulted in significant savings in heating and cooling energy in the food court and retail areas. Low volatile organic compound carpet, paints and other materials were used in the tenancy refurbishment.

BUILDING MANAGEMENT AND CONTROLS	Part of the control strategy to reduce energy was to implement a system that would clearly identify where and how much energy was being consumed. Energy metering on the major plant was subsequently installed, allowing better levels of monitoring and making it easier to pinpoint any issues. An external service provider dials into the system, analyses the data and reports monthly on issues and anomalies within the data. Several points in the BMS were made into variable points to enable tuning and manipulation by operators to improve the building performance and energy efficiency. Key sensors to the control systems (supply air temperature and system pressure) were recalibrated and relocated to improve reliability and accuracy. Paul Vandervlis, Senior Engineering Manager of Jones Lang LaSalle who was with the building project team during the planning to commissioning phases confirms that significant energy savings have been made through a concerted effort to improve the control systems.

The project team had a clear idea of the building's potential for optimism however communicating this effectively with and between consultants and contractors was sometimes challenging.

For the project team, the challenge in this project was getting the installed equipment and control strategies working and tuned correctly post commissioning.

An external technical agent from A.G. Coombs was brought in to assist with the tuning of the building performance strategies. They did not introduce performance-based contracts because of the amount of additional work going on at the same time. It would have been difficult to separate the contribution individual component projects were having on the whole energy performance unless all work was rolled under the same contract.

The commissioning process took over a year as there were challenges getting the BMS strategies running effectively. There were also many complex control strategies that needed seasonal tuning.

Parts of the installation works had several technical issues relating to latent conditions, and there were differences in perception of scope.

The site documentation was not up-to-date. This was a problem in so far as it meant not knowing whether the new control strategy would in fact negatively impact the operation of a different component of the complex system.

The project team adopted the approach to write the documented programming specification in the format of a revised building technical manual. This made clear what changes were required to all elements of the program. This also assisted in having accurate as-built manuals on these complex strategies.

Keeping occupancy rates up were also a challenge. This relates to the NABERS Energy rating as it is calculated on the energy used, square meter age occupied and the hours of operation.

In other words, to gain a significant rating, the building needs to be substantially occupied.

Table XIX. Main achievements of 385 Bourke Street, Melbourne.

NABERS ENERGY	Previous: 0.0 Current: 3.5 Target: 5.5
NABERS WATER	Current: 3.5 Target: 4.0
KEY REFURBISHMENT FEATURES	Upgraded BMCS. Variable speed fan drives. Economy mode. Lux meter sensors. T5 lamps. Quantum heat pump units. Flow restrictors in washrooms. Commingled recycling program. Metering.
ENERGY SAVING	372 MJ/m ² per annum saving which is a 41% reduction in CO ₂ .
GREENHOUSE SAVING	4.680 tonnes CO ₂ /annum

Figure 47. 385 Bourke Street. Facade.

Figure 48. 385 Bourke Street. Hall area.

Figure 49. 385 Bourke Street. Building reception area.

Figure 50. 385 Bourke Street.
Workstations.

Figure 51. 385 Bourke Street.
Reception floor area.

Figure 52. 385 Bourke Street.
Restaurants area.

CASE STUDY. LEGACY HOUSE, MELBOURNE.

Table XX. Main data of Legacy House, Melbourne.

BUILT	1937, last refurbishment 2006
NLA	Office 1.600 m ² approx.
TENANCY	Office
BUILDING OWNER	Legacy Melbourne
PROPERTY MANAGER	Legacy Melbourne
PROJECT TIMELINE	2013
PROJECT TEAM	Project Manager: Peter Samers (Legacy house). Lighting consultants: D2 LED Lighting & Design.
MAIN ISSUES	Inconsistent uniformity of light distribution (some areas over or under lit). Lighting represents a significant operational cost for owner and tenants.
PROJECT COSTS	\$ 47.000

Heritage listed Legacy House was constructed in 1937. Work to upgrade the building's interior, which had become run down and tired commenced in 2006. In 2013 a major retrofit was completed and has refreshed the look and improved amenity for building users.

Motivation to retrofit included:

- Reducing energy bills due to escalating electricity and maintenance costs.
- Reducing the excessive number of overhead lights in some areas to save costs.
- Improving lighting levels in under lit hallways and bathrooms.
- Better showcasing the Legacy memorabilia in the main entrance.
- Illuminating street canopy.

Project objectives included:

- Maximising tenant retention.
- Improving lighting uniformity and compliance.
- Reducing energy bills.
- Reducing operating cash flow.
- Improving amenity and saving money while achieving a commercially viable return on investment.

Legacy Melbourne commissioned lighting consultants, D2 LED Lighting & Design to undertake a 3-stage approach to the lighting retrofit.

A lighting assessment was conducted to benchmark existing lighting levels and performance and to inform optimal internal lighting design requirements. In addition to the visual assessment, existing plans/drawings helped to identify current issues and challenges.

Dialux modelling and 3-dimensional renders were used to develop the Reflected Ceiling Retrofit Plan. The Plan sets out the optimal layout for compliance with Australian Standards AS1680. The Plan maximises potential operational savings while simultaneously improving building performance.

The new lighting design identified that the existing number of lighting fixtures could be reduced by 17%. This would be simultaneously improving lighting levels and amenity while reducing energy consumption by more than 60%.

About employee productivity, the reaction from workers has been positive with consistent reports of increased productivity due to reduced levels of eye strain by the replacement of flickering fluorescent lights with better performing LEDs.

Staff also enjoy the brighter ambience and more comfortable lighting conditions.

Tenants of Legacy House are pleased with the lighting retrofit as it has provided them with better working conditions which supports improved staff productivity. More efficient lighting fixtures combined with a reduced number of luminaires has improved operating cash flow through reduced electricity costs.

This has greatly enhanced the tenant/landlord relationship. Finally, Legacy House refurbishment achieved:

- A 64% reduction in electricity consumption.
- Lower operating costs.
- Compliance with AS1680.
- A reduction in the total number of lights by 16%.
- A total reduction of electricity consumption of 7.241 kWh over the first 72 days.
- \$8.500 per year savings.
- Reduction in carbon emission of 57 tonnes per year.
- Reduction in landfill waste of 5.250 lights over 12+ years.

Figure 53. Legacy House. Facade.

Figure 54. Legacy House. Reception area.

CASE STUDY. ROSS HOUSE, MELBOURNE.

Table XXI. Main data of Ross House, Melbourne.

BUILT	1897 (Heritage listed)
NLA	2.120 m ²
TENANCY	6 storey office building consisting of basement (car park), a small retail shop on the ground floor, 5 office floor levels and a roof plant room.
BUILDING OWNER	Ross House Association.
PROPERTY MANAGER	Ross House Association.
PROJECT TIMELINE	2009-2014
PROJECT TEAM	Building Environment and Amenities Sub-Committee; Hyder Consulting (Opportunity report); Arup (Environmental Management Plan).
PROJECT COSTS	A full implementation of the Opportunity Report, is estimated at about \$250.000. It is estimated that it will cost \$500.000 to meet NABERS Energy rating objectives.

The Heritage and National Trust listed building, located at 274 Flinders Lane in Melbourne, was constructed in 1898 as a grand six storey warehouse. The original Sargood importer warehouse stretched from Flinders Street to Flinders Lane, as part of the warehouse precinct that occupied this area. In November 1897, a fire destroyed the warehouse.

Sargood engaged Sydney architects Sulman and Power to redesign the warehouse. The building was designed as a brick structure using a Romanesque style, with giant brick arcades, metal oriel windows and parapet colonnade. It was a massive six storey structure, but unfortunately just as it was completed, another fire destroyed half the building.

Once again, the building was restored, this time with fire sprinkler systems, fireproof doors, a flat concrete roof and window drenchers. The oriel windows were also recessed as a fire prevention measure.

In 1931, the building was acquired by the State Electricity Commission of Victoria and converted to offices. In the mid-1930s, the Flinders Street half of the building was demolished and new offices built, but the Flinders Lane half was retained. It was named Royston House.

Ross House, as it was re-named, opened in 1987. The building was purchased through a substantial grant from the R.E. Ross Trust. Since 1998, the building has been managed by Ross House Association, which offers low rent to tenants; mostly small, independent community and self-help organisations committed to social justice and environmental sustainability.

Its last refurbishment took place between 1985-87, during which all systems were upgraded, including the HVAC, which was converted from a centralised system to individual units on each floor.

In 2008 Ross House participated in a pilot retrofit program run by the City of Melbourne in partnership with Sustainability Victoria, called the Building Improvement Partnership Program.

Hyder Consulting was appointed to review the building's operational efficiency and to recommend improvements. Hyder Consulting released an Opportunity Report in 2008. It made several recommendations, which if implemented, could reduce greenhouse emissions by 22-34 %.

As the building is heritage listed, the Ross House Association (RHA) commissioned a Conservation Management Plan (CMP) so that changes could be made to the building while still meeting the heritage conditions.

The long-term objectives are to completely overhaul all systems, and to bring the building to at least a NABERS 4.0-star level. In the meantime, the Building Environment and Amenities Sub-Committee are following the recommendations provided in the Opportunity Report, and implementing these where practical.

The tenants are unanimously supportive of the Association's objectives to 'green' the building, as they share the philosophical position of the management committee. The management would like to see the building at the leading edge of green design and operation.

The Opportunity Report is not a technical specification; it highlighted areas that needed upgrading or replacing, or where other cost savings can be made, so an Environmental Management Plan (EMP) was commissioned. The international sustainability consultants, Arup, have offered to produce an EMP at a cost rate, and the Ross House Association has just secured the funds from the R.E. Ross Trust to pay for this work.

The EMP will be the blueprint for greening the building, and will include big-ticket items such as replacing the HVAC, overhauling the lighting, installing sub-metering and a building management system (BMS).

The Building Environment and Amenities Sub-Committee will manage the process, and recommendations will go to the RHA management committee for final approval. Depending on funding, it may be necessary to run the project over four years, and renovate a floor at a time.

Any refurbishment will also need to consider heritage conditions. These were revealed in a comprehensive Conservation Management Plan (CMP).

Several the most accessible and easily implemented recommendations made in the Opportunity Report have already been completed. It is anticipated that other recommendations will be completed during 2011-12. However, any substantial retrofit awaits an Environmental Management Plan and some of the Opportunity Report recommendations will not be implemented in lieu of the EMP.

Figure 55. Ross House.

Figure 56. Ross House. Facade.

Figure 57. Ross House.

Figure 58. Ross House. Stairs.

Table XXII. Architecture features of 385 Bourke Street, Melbourne

BUILDING	Ross House is a five-storey building with approximately 2.120 m² of net tenable space. As the building must meet heritage conditions, there are limitations regarding changes to the building fabric. The façade of the building dates to 1901, so there is a good deal of air leakage. The CMP found that areas of primary significance include the Flinders Lane elevation (retaining its original masonry structure and window joinery), the bluestone entry stairs and the original internal window joinery. However, the CMP has advised that very few internal structures need to be preserved.
HVAC	Currently, the air conditioning system consists of Direct Expansion (DX) Air Handling Units (AHU's) located on each floor level, distributing conditioned air through two high level ducts into the office space. Each floor level is divided into two zones, with individual AHU's, using DX compressors, serving each zone. A single cooling tower rejects the heat from the AHU's via the circulating condenser water. The heating water is currently supplied by one single natural gas fired boiler. The boiler was installed when the building was refurbished in 1986 and is located on the roof. Other than regular maintenance such as keeping the duct work clean, there is no real way to significantly improve the HVAC energy efficiency. Time clocks allow the system to be automatically switched on and off, but it lacks other efficiency measures such as effective zoning, night refresh, economy cycle and variable air volume (VAV) fans. The Opportunity Report recommendations included after-hours air conditioning control (not completed), variable speed drive (VSD) on cooling tower fan (not completed) and upgrading the existing time-clock to run toilet exhaust fan at different times to air handling unit (AHU) plant (not completed). However, the current system has reached the end of its life-cycle, so it needs to be replaced, and the management has deemed it not cost effective to make piecemeal changes to the system at this stage.

ENERGY LOAD	A tenant survey was conducted on how tenants use energy in the building, to get a sense of the energy load. Heating relating to lighting is difficult to control as lighting is not provided office by office; there is a single electrical main retail supply meter for the office accommodation and car park areas. A second retail electrical meter serves the ground floor small retail tenancy shop. The Opportunity Report recommended putting switches in each office, and this will be implemented in 2011 (budget permitting). Domestic hot water is supplied by local electric hot water storage units located on the first and third floors for the male and female toilets at the south end of the building. Individual small electric hot water storage units are located on each floor serving the disabled toilets and kitchens on the north end of the building. Boiling hot water in each floor kitchen is supplied from local electric instantaneous hot water boiling units. The Opportunity Report recommended the installation of time-clocks for each instantaneous boiling unit, and this has been completed.
WATER	The Opportunity Report found that Ross House was already very water efficient with an unofficial 5 star NABERS Water rating, based on a 12-month period between May 2007-May 2008. The Opportunity Report recommended upgrading to waterless urinals, which has been done and installing flow restrictors on all existing hand basin tapware, which has not yet been completed.
WASTE	The tenants are encouraged to segregate waste into recyclable and non-recyclable materials, and the building cleaners empty these bins located at the end of the hall every day. Signs are provided to ensure tenants segregate their waste correctly, and management is hopeful that with the retrofit project about to commence, tenants will engage more with the whole greening exercise.

ENVIRONMENT	As the tenants of the building are focused on community and environmental causes, the Ross House Association staff engage tenants in environmental campaigns, calendars of events, and discussions about what to do with the building spaces, such as the foyer. This is all aimed at making Ross House a more inclusive and pleasant place to work.
BUILDING MANAGEMENT AND CONTROLS	There is no building management system (BMS) in the building, and only one electricity meter for the whole building. The HVAC system is run on time clocks. The Ross House facility manager has created charts of energy and water use over recent years, and discussed with tenant's ways to achieve less load on the system. However, energy-reduction strategies are limited by the building systems and the lack of individual tenant controls, as it is not currently possible to split off individual floors or zones. The Opportunity Report recommended installation of a simple small BMS to control air-conditioning services and possible lighting control. However, this will be reevaluated in the EMP. It was also recommended that Ross House monitor and review ongoing energy and water consumption from invoice data monthly.

The main challenge for the Ross House Association is raising the money necessary for a retrofit. As Ross House is a not-for-profit institution offering low cost rental space to community organisations, funds for refurbishment are not easy to generate, and the Association is seeking grants.

The estimated cost to bring the building to a NABERS 4.5 rating is approximately \$500,000.

The other challenge is ensuring that the building adopts, based on professional advice, the most effective system that will meet the green objectives and tenant comfort at an affordable cost.

There are some learned lessons in this project. According to Steph Donse, Ross House Development Officer, making informed decisions when embarking on a project as costly and complex as a retrofit is crucial.

For a heritage building such as Ross House, the Conservation Management Plan is very important, because it gives a comprehensive picture of the state of the building and what can and cannot be done within the heritage conditions.

Seeking advice from reputable engineers and architects who will help find a unique solution has also been an important lesson, and this means doing research to find the right consultant, examining their experience and credentials and looking at the buildings they have worked with previously.

CASE STUDY. 406 COLLINS STREET, MELBOURNE.

Table XXIII. Main data of 406 Collins Street, Melbourne.

BUILT	1958-1961
NLA	4.000 m ²
TENANCY	Offices, Telstra retail store.
BUILDING OWNER	Dr Dorian Ribush
PROPERTY MANAGER	Colliers International
PROJECT TIMELINE	2008-2011
PROJECT TEAM	Project manager: Dr Ribush; consulting engineer: RC Lister Engineering Pty Ltd.; contractor: Blue Planet Electrics.
PROJECT COSTS	\$ 1,5 million
KEY REFURBISHMENT FEATURES	MITSUBISHI Variable Refrigerant Volume (VRV) air conditioning system. Zoned floors. Economy cycle dampers. Automated night flushing. Roof sunshade. Internal and external shading in courtyard. Motion light sensors in stairwells and lifts. High efficiency lighting in common areas. Sub-metering system. Web enabled building management control system. (BMCS).

This site has been built upon since the 1840s. In 1897, a grand building was constructed in typical Victorian style, as the headquarters of the Mutual Assurance Society of Victoria. In 1958, the old building was demolished and in its place, a new modernist six-storey building was constructed.

This was typical of a late 1950s "skyscraper" design – built from a steel and concrete structure, plain (non-ornamented) facade, with a strip of windows on each floor facing Collins Street.

The building was enlarged in 1961, when four more storeys were added. The only original feature remaining from 1897 is the 'Atlas' statue, which was originally featured in the decorative pediment at the top of the old building. It is now located at the street level adorning the building entrance.

The building's heating, ventilation and cooling (HVAC) system was typical of the 1960s: the aim was to minimise capital cost while providing relatively good working conditions, but there was no concern for energy efficiency – at the time, energy was cheap.

The building has 4000 m² net lettable area (NLA), including a Telstra retail store on the ground floor, and eight tenants that occupy at least one floor each. The floor plate is rectangular, measuring about 350 m² on each floor. The HVAC system had clearly reached its use-by date. Modification of the existing system was not considered to be a viable option to achieve a significant improvement on energy efficiency.

A large central boiler provided the heating, and a central chiller located on the roof provided the air conditioning. Due to a quirk of history in 1961 when four additional floors were added to the original six, the air handling provided to the first six floors was from the basement, and the top four floors from the roof.

So, while the boiler and chiller supplied the whole building, the air circulation and fresh air intakes operated as though the building was in two separate parts.

Even on a very hot or very cold day, both the boiler and chiller operated - which is a very inefficient way to operate an HVAC system.

At about the same time as Dr Ribush started to investigate ways to improve the energy efficiency of the building, the City of Melbourne launched the Building Improvement Partnership Program (BIPP).

Under this scheme, a large consultancy was engaged to conduct an audit of the building, and a set of recommendations was made, which included completely replacing the HVAC system. Dr Ribush was critical of the quotes that were provided and obtained a second opinion.

In 2009, Dr Ribush applied to the Australian Government's Green Building Fund, which provided matching grants of up to half a million dollars for energy refurbishment projects. For the purposes of the application, the building was then rated 2.0 stars National Australian Built Environment Rating System (NABERS) Energy.

The application was successful and with the total cost of the works of about \$1.5 million, the retrofit went ahead.

The main objectives of the retrofit project were to:

- Improve the energy efficiency of the building
- Achieve at least a 4.0 star NABERS Energy rating
- Reduce the carbon footprint and once the energy consumption was reduced, use green power sources.

On receiving the Green Building Fund grant, the first task was to investigate the best way to implement the HVAC refurbishment.

The City of Melbourne referred Dr Ribush to the Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH) to appoint the consulting engineer, Mr Dick Lister. Together they worked on the Green Building Fund application. Mr Lister shared the same 'hands-on' approach as Dr Ribush and was willing to find solutions along the way.

This was considered preferable to employing a large contractor that would come in and do the whole job under time pressure. In a fully tenanted building, significant tenant engagement and consultation, and a lot of timetabling and flexibility was necessary while the works were underway. Consequently, a floor-by-floor approach was chosen to minimise disruption to tenants.

This decision also meant adopting a HVAC system that could be introduced floor by floor. Instead of a centralised system, a split unit system servicing each floor was chosen, so that each floor was effectively self-contained.

Each unit was located on the roof, with copper pipe running down the riser or stairwell to that floor, and supplying the indoor air-handling units at that level.

This solution simplified the installation process: craning a chiller and boiler on the roof was not required. Instead they could bring the units up in a lift and the front stairwell.

Other options such as variable air volume (VAV) were incompatible with the ducting infrastructure of the building, or would have taken up valuable floor space for the installation of air handling units.

The consulting engineer provided a comprehensive design plan for the system prior to engaging the installation contractors. Mr Lister had previously worked with a small refrigeration service company, Blue Planet, who were engaged as the HVAC contractors.

Blue Planet has a team of five or six men who understood the approach Dr Ribush and Mr Lister were taking; to trouble shoot as they proceeded on a floor-by-floor basis. It was very apparent as they started work that each floor had a different problem, typical of buildings of this age. The location of the kitchen, the plumbing, the ductwork and so on, was different for each floor, so having a rigid installation plan was not possible or practical.

The contractors undertook special training with Mitsubishi, the vendors of the HVAC variable refrigerant volume (VRV) units that were subsequently installed. Mitsubishi Heavy Industries was also contracted to commission the units once they were installed. Dr Ribush became the project manager and oversaw the project scheduling, rubbish removal, fire services arrangements, tenant liaison and made decisions on the placement of equipment.

To minimise tenant disruption, the work commenced at 6 a.m. and finished at 2 p.m., with any noisy or dusty work finished by 9 a.m.

Table XXIV. Architecture features of 406 Collins Street, Melbourne.

BUILDING	The building structure and façade was left intact, other than removing and replacing ceilings to expose the ductwork and to install new air handling systems. In the Case of the ceilings, it was found that the original ceiling tiles were poorly installed and these were replaced by more modern methods where individual tiles can be removed without affecting the whole ceiling structure.
HVAC	The decision was made to install a zoned Mitsubishi VRV air conditioning system. Each floor is divided into four or five zones that can be controlled independently. There is a total of 10 outdoor condensing units, with an average of four or five indoor fan coil units (FCU) per floor. In addition to the new VRV system, extra economy cycle dampers on each floor are installed to allow for the relief of warm return air to atmosphere, thus alleviating load on the FCU. Each floor has an isolating damper installed on the supply air to ensure that the outside air fan only runs fast enough to supply the required air volume. Mr Lister views the system solution that was installed as being the most cost-effective for a building of this size, and one of the objectives of implementing this is to provide an example for other buildings of this type. The building will be 'night flushed' in summer and winter as part of the current project. This will use an automated system to measure the relative inside and outside air temperatures, and between 5am and 7am will draw air in from outside to flush the whole building and rid it of stale air. The chiller and boiler will both be removed. It was necessary to retain them during the refurbishment so that un-renovated floors could be cooled or heated using the old system. In other words, a dual system was operated throughout the project.

ENERGY LOAD	The building is hemmed on the east and west sides by other buildings, so the thermal loading from these directions is minimal. Other buildings provide shade on the northern aspect to level six, which prevents solar gain on most levels below. Above this height, there is direct sunlight. The southerly windows, where there is negligible direct sunlight, are small in comparison to modern 'glass block' high-rise buildings and are double-glazed for noise insulation rather than thermal comfort. On floors nine and ten, there is a small eastern facing courtyard indented in the building, and both external and internal shades have been introduced on all windows to deflect direct sunlight. A sunshade has been installed over part of an exposed roof (about 65 m²) and this has substantially reduced the heat transfer through the roof to the tenancy directly below. The sunshade is constructed from a layer of 90 per cent shade-cloth stretched about a metre above the roof, allowing both shade and ventilation. It's a cheap and effective solution. Motion sensors have been integrated into the stairwell lighting, as well as in the lifts. All use low voltage lamps. These lights were previously on 24 hours a day and are now off most of the time. This contributes both to lowering electricity consumption and heat load. The lights in the high ceiling foyer have been hung lower which enables services from a ladder rather than a cherry picker. This also means that the lights need to be less bright. Mirrorlux reflector lighting has been introduced into several tenancies. These employ a highly polished aluminium reflector behind a higher output fluorescent tube. The result means that one or two tubes can be removed from the fluoro set.
WATER	Conventional flushers have been set to ensure the minimum amount water is used to suit the function. Aerators have been introduced in the hand basins to reduce high water consumption.

WASTE	The tenants are cooperating with the waste separation system sorting into recyclable and landfill containers. The cleaning providers have been trained to manage this system. Occupants are provided with a cardboard box by each work station, which only permits the disposal of recyclable waste. Other waste, such as food scraps are deposited in separate containers in the kitchen areas. Paper towels are used in bathrooms, and recyclable paper is used for hand drying in toilets and hand basins.
ENVIRONMENT	Where possible, green cleaning products are used. The building management allows tenants to take bikes in the lift into their tenancy. This encourages the use of bicycles as a mode of transport. They are now investigating the practicalities of installing bike racks in the basement.
BUILDING MANAGEMENT AND CONTROLS	Prior to the refurbishment project, the building had essentially no HVAC controls. It was an analogue control system that lacked calibration, with about 20 per cent of the controllers faulty, and many wiring errors from years of poor maintenance. The time clocks were not optimised to accommodate holidays or weekends. There was simultaneous heating and cooling, both during winter and summer. This inefficient system has been replaced by an up-to-date building management and control system (BMCS) with building automation and control networks internet protocol (BACnet IP) controllers, open architecture, ethernet based, internet enabled and integrated with the new metering system for real time feedback about how the building is performing. Not satisfied with data from existing utility meters, a complete sub-metering system was installed that collects comprehensive data every half hour and is stored on a remote structured query language (SQL) database which allows around the clock access from any location. At present, each floor operates independently, but when the whole building is completed, there will be an interface which sets all the units on timers – business hours (8am - 6pm), public holidays and so on- and a key switch that tenants can activate after-hours if they need to use the space air conditioned (operating at 2 hour periods). This will be metered and the tenants will be charged separately for afterhours use. The BMCS will track power consumption and cost for the tenant. The BMCS has a web interface, making it possible to see what the temperature and other conditions are, floor by floor, zone by zone, and to adjust off-site.

The main challenges for the project team were dealing with the difficulties typically encountered in old buildings, and the need to maintain the existing services in a fully tenanted building during refurbishment work.

According to Dr Ribush, another major challenge is managing cash flow during the project. Initially he tried to fund the project from cash generated from the ongoing rent, but found that this did not meet the expenses. The Green Building Fund grant that he received provided \$500,000 for the whole project, but just \$100,000 up front.

The rest is given on project completion. To make up the shortfall, he secured a loan from Sustainable Melbourne Fund (SMF).

To meet the costs, this project could not have proceeded without the building being occupied: otherwise the process is just too costly. So, the challenge was to minimise the impact of the works on tenants.

The floor by floor implementation of the VRV system is compatible with this objective. But it was still necessary to provide air conditioning to those in the remaining floors that were not yet refurbished, which meant operating a dual system across the whole project.

Liaising with tenants was crucial. There is always noise, dust and disruption in any building undergoing major retrofit, particularly for tenants when their floor is being worked on. This requires a good deal of goodwill and cooperation, which is not always easy to achieve.

There were many difficulties with the building itself, which was not unexpected given it was constructed 50 years ago, and where four floors were added to the original six.

A lot of the insulation on the hard metal ductwork that ran from the units into the tenancies to outlets in the ceiling had disintegrated. Fixing this entailed many additional hours of work, re-insulating or tying it back up to reinstate the insulation, otherwise heating and cooling would have been lost in the ceiling.

A lot of the ceiling tiles also had to be replaced as the old ones were not installed well; when one was removed, many others were dislodged.

There are limitations on the ratings that can be achieved in older fully occupied buildings. Dr Ribush hopes to obtain a 5.0 NABERS Energy rating, but the difficulties may limit this to 4.5. However, 4.5 NABERS Energy is an outstanding achievement in a building of this age.

Table XXV. Architecture outcomes of 406 Collins Street, Melbourne.

ENERGY	Performance measures have not yet been conducted as the new system has only just been installed. However, based on measurements made on floors that have the new system installed, Mr Lister is confident that energy consumption will be halved or even as low as 25 per cent prior to the retrofit.
WATER	The building has low water use and achieved a 5.0 NABERS Water rating.
SOCIAL	Mr Lister believes a significant challenge in the project is tenant comfort. With the new system, there will be perceptible variations in the internal temperature range, in both summer and winter. Educating tenants to accept slightly warmer ambient temperatures in summer and cooler in winter will allow significant energy savings.
MAINTENANCE	This is yet to be determined, but with the HVAC improvements made and the installation of the BMCS, the engineers and building management is confident that the maintenance will be speedier and less costly.
COMMERCIAL	Although it is highly likely there will be significant energy improvements, Dr Ribush is not certain that there will be direct financial returns on his investment. The viability of the project hinged on the Green Building Fund grant. Without it, he doubts that the project would have been as extensive, and it would have meant an even lower return on investment.
OVERALL	It is still too early to tell, but the signs are very promising that the building will achieve a 5.0 NABERS energy performance level.

LESSONS	Dr Ribush believes it is inherently difficult to improve energy efficiency in tenanted, older small buildings in Melbourne. He believes this can be best accomplished by paying special attention to good communication with tenants, and providing a sensitive implementation of upgrade works. In small, older buildings, a significant refurbishment can only be done while the building is occupied to maintain a cash flow. This requires a lot of planning to complete the project within a reasonable timeframe. The other option of refurbishing around a tenant vacancy strategy is not practical for this type of building, as tenants may not move for years and this would extend the project unacceptably. Indeed, the Green Building Fund, which enabled this and many other projects, requires the building project be complete within two years. Knocking a building down completely and starting again ignores its embedded energy and the usefulness of the original structures, and many older buildings cannot be demolished because of their heritage listed. Dr Ribush believes the best prospect in encouraging buildings of this age, size and standard is for the City of Melbourne to facilitate cooperative ventures involving adjacent buildings in a precinct, sharing expertise and technology. Mr Lister agrees that it is crucial to have tenant buy-in to the project from the outset. The HVAC performance history of this building was very poor; the tenants were therefore antagonistic and somewhat sceptical of improvements, and it was vital to overcome this. It was important to convey to tenants that because of the refurbishment, there will be better air quality, reliable conditioning of air and lower energy costs.

Figure 59. 406 Collins Street. Facade.

Figure 60. 406 Collins Street. Entrance.

Figure 61. 406 Collins Street. Hall area.

CASE STUDY. 131 QUEEN STREET, MELBOURNE.

Table XXVI. Main data of 131 Queen Street, Melbourne.

BUILT	Originally early 1900's – new floors and façade built in 1930 - 1950's over two stages.
NLA	5830 m ²
TENANCY	Offices, Buddhist Art Gallery and Café. Turf Accountants Bar & Restaurant.
BUILDING OWNER	11 different owners, forming an Owners Corporation
PROPERTY MANAGER	Quayles OCM
PROJECT TIMELINE	2008-2011
PROJECT TEAM	Quayles OCM Quantum Facility Management WSP Lincoln Scott AE Smith BENT Architecture (Green Roof design)
PROJECT COSTS	\$1.5 million
KEY REFURBISHMENT FEATURES	Sealed roof membrane High efficiency chiller Variable speed drive (VSD), air handling unit (AHU) Economy cycle Digital Building management system (BMS) Award winning rooftop garden

The Victoria Club was founded in 1880 by bookmakers who broke away from Tattersalls Subscription Betting Rooms. At the club, the card was called and bets were settled.

The Victoria Club flourished and by 1926 had purchased quarters at 131 Queen Street where it stayed for about 60 years.

On 21 April 1976, its settling day was brutally disturbed by the Great Bookie Robbery, during which a well-organized gang of six stole between six million and \$12 million. The men; Prendergast, Kane, Kane and Lee, rented an office in the same building and hid the money there while making a fake getaway in a van. The money was never recovered and although Lee was charged he was later acquitted. None of the others were ever convicted. Lee was killed by police in 1992 during a heist at Melbourne Airport.

Lee's lawyer Phillip Dunn, QC, revealed the details of the crime in the mid-1990s, including the identities of all those involved. Prendergast disappeared in 1985 and the rest of the gang had all been murdered by the end of 1987. As no one was ever jailed or convicted, the Great Bookie Robbery remains technically an unsolved crime.

Originally built in the early 1900s, 131 Queen Street is now classified by the Building Trust as a 'building of interest.' The original building was an emporium of three storeys, but in the 1930s and 1950s, another eight levels were added in two stages. A completely new façade was constructed in 1955, architecturally reflecting the bygone period of the eighteenth century.

The building now boasts the Turf Accountants Bar and Restaurant downstairs, an art gallery, tea rooms and prayer room owned by the International Buddhist College of Victoria and Open University Australia on the two lower floors.

The ownership of the building is unusual because it is owned by 11 independent organisations on a strata-titled basis with the majority being owner-occupied. Tenancies range from multiple floors to a single office.

The eleven floors have a total of 5830 m² net-lettable area (NLA), which includes the basement, mezzanine and upper ground floor, plus eight levels of office space.

Since the 1940s, there have been various upgrades and modifications to the mechanical systems in the building with heating, ventilating, and air conditioning (HVAC) introduced in 1977.

Amanda Black, one of the owners, is the Owners Corporation (OC) Manager, supported by Building Manager Peter Maskiell and Ashley Wakefield from Quantum Facility Management Direct.

The refurbishment project began in 2008 and was completed in 2011.

There were three main objectives in retrofitting the building:

- To completely bring to standard the safety and essential services (smoke detectors, fire equipment, fire and smoke doors)
- To convert it to a green building, aiming for a 4.0 – 4.5-star National Australian Built Environment Rating System (NABERS) rating.
- To significantly reduce running costs by focusing on preventative maintenance.

The refurbishment process began when the building management team investigated in 2008 into every aspect of the building - its essential services (fire procedures and equipment), HVAC and plant rooms.

The investigation found there was no current essential services certificate of compliance or any indication of when compliance had last been achieved.

The team took on board the accumulation of many years of tenant complaints, particularly about the air conditioning. They talked to contractors and examined all the building documents. They found that the servicing was not being conducted properly, so opted to change the contractors.

The new contractors delivered a report on the HVAC which indicated the system was well past its use by date; was very energy inefficient and was not providing tenant comfort.

It was a centralised system that had been installed in the 1970s, and broke down at least once a week. A lot of money was being spent continually fixing it because preventative maintenance was not conducted.

Building management compiled their findings in a report to the owners' Annual General Meeting in 2009. The report contained recommendations and quotes, foremost amongst which was the need to make sure the building met the regulations on essential services (safety) and fire systems. It was not easy to get all the owners to agree on all issues.

The Buddhist College and Open Universities Australia had already spent a lot of money upgrading their part of the building out of frustration with the general building up-keep.

It took about 12 months to get all the owners to agree, by providing information and reiterating the benefits of investing heavily in the future of the building. The management team could show what was wrong and what needed to be fixed, but they had to justify why the retrofit was necessary.

A good deal of their argument was based on personal safety, the wellbeing of occupants and ensuring the owners recognised their obligations under various Acts.

When agreement was finally reached, the operations team applied for and received a Green Building Fund grant from the Australian Government of \$500,000.

As part of this process, an assessment was conducted and the building received a zero NABERS rating. The retrofit cost about \$1.6 million, which included a completely new fire panel and HVAC system as well as installation of energy efficient light fittings and globes in most of the common areas.

The HVAC upgrade also necessitated an increase in the capacity of the mains cable to the new roof plant and equipment and provided the opportunity to install safety switches to the main electrical switchboard, which had been of concern to owners for many years.

The OC hired an engineering contractor, Lincoln Scott, to produce a set of tendering documents and design specifications for the upgrade of all the mechanical systems.

The tender received applications from four companies. To meet Green Building Fund conditions, the project had to be completed within 12 months, which also included the commissioning.

The planning took about six months to accomplish and with hindsight, the OC would have preferred more time at this crucial stage. A suggestion along these lines will be made to Aus. Industry in the final submission regarding the Green Building Fund.

AE Smith was appointed as the successful major contractor. The project took about eight months to complete. The old HVAC system was disconnected in October 2010.

To minimise disruption to the occupants, most of the HVAC upgrade was done at night which unfortunately added to the overall project cost but was unavoidable in a fully occupied building. The project is currently in the commissioning, fine-tuning and balancing stage, now that the installation of all systems has been completed.

Figure 62. 131 Queen Street. Facade.

Figure 63. 131 Queen Street. Entrance.

Table XXVII. Architecture features of 131 Queen Street, Melbourne.

BUILDING	The top six floors of the building that face east receive the hot morning sun in mid-December and January. Four large buildings provide shade on the other sides. The project team considered tinting the east facing windows, but this was considered too expensive. This option may be revisited at another time though industry speculation regarding the redevelopment of the south-east corner of Bourke and Queen streets may see the matter taken out of the owners' hands should those buildings be increased in height. The rooftop membrane of the building had to be redone because of rust found within the concrete which was leaking water into the building. Very little preventative maintenance had been conducted for years, and the tenants below were constantly complaining of rainwater seeping into their space. There was no need for any other internal work other than replacing the air conditioning ducting on some of the floors. With the change of HVAC, the upper floor plant room has been significantly reduced in size, and the additional space will be used as an office for the operations team.
HVAC	The HVAC refurbishment was complicated in that the first and second floors had installed their own system during refurbishment in 2005. A separate system, which serviced the basement, foyer and upper ground level, had undergone significant repairs in 2009 and the owners are committed to also replacing this system when the funding and operational needs are established as a second stage project. For floors three to eight, a completely new HVAC system was installed with the plant operating from the rooftop. It is a combined electrical and gas centralised system, which features: - A high-efficiency electric chiller. - Air handling with variable speed fans. - Six zones across each floor that can be independently controlled. - An economy cycle managed by the digital control system where outside air is brought in if it is cooler than set point; the damper is automatically opened to draw in fresh air from outside. - Heating using a gas boiler to pipe hot water through the building, coils in the floors and air that blows over these.

ENERGY LOAD	There are few common areas where lighting can be made more efficient, and it is difficult to impose lighting solutions upon all the owners and tenants because they pay for their electricity costs independently. Nevertheless, the stairwells and common area hallways have all be fitted with T5 fluoro lamps, and motion sensors have been installed at all possible points.
WATER	The common areas of the building have very low levels of water consumption, so this has not been given attention at this stage.
WASTE	The waste program is limited by the owner and tenant structure of the building. There is a tendency from the past for occupants to follow their own arrangements. The building management team encourages waste recycling, and is promoting a 'family feel' for the building to encourage owners to feel that they share the whole building, not just occupy one space within it.
ENVIRONMENT	In 2009 the Committee for Melbourne's Future Focus Group, a professional development program for young leaders, initiated a competition (Growing Up) for the design and installation of a green roof on a Melbourne commercial building. The building at 131 Queen Street, and its winning design by BENT Architecture, best exemplified the environmental and amenity benefits, as stated by the chair of the judging panel and Victorian Government Architect, Geoffrey London. The rooftop garden at 131 Queen St was opened in July 2010. Tenants in the building can use the rooftop for lunch, meetings, private functions and the building Christmas party. The rooftop garden is open to the public on Melbourne Open House weekends. The garden has a gazebo and BBQ area, low maintenance herb garden and small plants including lavender, a lemon tree, olives and strawberries. The roof cannot bear larger trees because of the weight. A volunteer gardener (with help from the building management team) looks after the garden. The roof garden provides many benefits including: mitigating against the urban heat island effect; provides a filtration system for storm water, insulates the upper floor of the building and provides a green recreational space for building occupants. At the rooftop garden launch, City of Melbourne Lord Mayor Robert Doyle commented:

BUILDING MANAGEMENT AND CONTROLS	A Building Management System (BMS) was installed along with a digital control system throughout the building. This system senses the building's indoor environment, and starts the air conditioning when it is necessary. This is very different to the old system, which was on a timer system and came on whether it was needed or not. The BMS has a graphical interface with diagrams of each floor zone, chillers, boilers and air handlers. It enables tracking of the system seven days per week and provides comprehensive reports on the energy consumption of all components. Part of the upgrade also included the fire dampers panel. It is intended that the BMS will also be used to measure the energy consumption of the building and provide invaluable data to the owners for base building and individual tenancy benefit.

The most challenging part of the refurbishment project, was communicating with the eleven owners and relaying information to them so that they were fully aware of the condition of the building and to get their initial agreement to go ahead with the works. The owners had to be convinced that the fire and mechanical systems were no longer repairable.

The building management team also had to ensure that on behalf of the owners they were getting value for money. It was an expensive outlay, and it was particularly important for the investor owners to ensure there would be a return on their investment.

Managing the building during the works was also a challenge due to occupancy. A high level of communication was necessary to inform the tenants when work was on and keep them up to date with what was happening.

An older building such as this always provides challenges. In this Case, as it was a fully tenanted building the ability to house the construction workers and their equipment was limited. The project team had to hire a space with kitchen and toilets, which was quite an expensive undertaking.

Another issue was revealed with the upgrading of the fire panel. It was discovered that although this was upgraded, it was not compatible with the older technology such as the damper, so this had to be upgraded as well.

Table XXVIII. Architecture outcomes of 131 Queen Street, Melbourne.

ENERGY	No formal measures are available yet because 12 months of data is required. However, the owners are confident that a 40 per cent reduction in electricity costs will be achieved.
WATER	Water usage in the building is already very efficient and no plans for improvement are proposed at this stage.
SOCIAL	Green garden amenity has provided many new social opportunities for owners and tenants.
MAINTENANCE	The new plant and equipment will yield significant savings on maintenance.
COMMERCIAL	Estimated \$50,000 per year saving on the energy bill and reduced maintenance bills.
OVERALL	The building management team is very pleased with the overall outcome, although they are yet to conduct a formal NABERS Energy assessment.
LESSONS	The main lesson to be taken out of this project is the need to make time in the planning stage for research. Unfortunately for 131 Queen St, this stage was stressful because of the conditions of the Aus. Industry grant and the complex construction of the building over three stages over the last 100 years. The Green Building Fund grant, while providing a life line to this ageing building, also presented a challenge to the owners. The grant is released in three stages, 20% on commencement, 60% on practical completion and the balance of 20% some 12 months after practical completion. For many owners, without very careful planning, this could create cash flow problems.

7. COMUNIDAD CIENTÍFICA

Alrededor del tema de investigación sobre métodos de cuantificación del impacto de los entornos de trabajo en las variaciones de productividad y bienestar de las personas, se encuentran principalmente cinco grandes grupos que componen la comunidad científica investigadora del tema.

En primer lugar, destaca Japón y la Universidad de Keio, con el laboratorio del profesor Toshiharu Ikaga, con numerosas publicaciones sobre este tema de investigación.

En Segundo lugar, dentro de Europa, este tema de investigación es liderado por el campo de conocimiento del Facility Management, dentro del cual destacan EuroFM y la institución internacional IFMA. Esta institución, de origen americano, enlaza con el tercer grupo de la comunidad científica, que sería Estados Unidos, con grupos de investigación sobre este tema en la Universidad de Harvard y en la Universidad de Carnegie Mellon.

Dentro de Europa merece una mención aparte Reino Unido, donde destaca la investigación hecha en la Universidad de Reading y en la universidad de Cambridge.

Por último, hay que mencionar la investigación llevada a cabo por certificaciones relacionadas con el bienestar en edificios, como WELL, Fitwell y Living Future Institute.

La Figura 64 resume los principales grupos que componen la comunidad científica investigadora del presente tema de investigación.

Figura 64. Comunidad científica relacionada con métodos de cuantificación del impacto de entornos de trabajo en las variaciones de productividad y bienestar de las personas.

8. CONCLUSIONES CAPÍTULO II

La oficina continuará cambiando en el futuro, como resultado de la adaptación dinámica a los diferentes estilos de vivir y trabajar, que responden al estilo de sociedad, su composición demográfica y sus valores. Sin embargo, no parece que las principales funciones vayan a cambiar, por lo que el uso de oficina continuará.

Los lugares de trabajo deben adaptarse fácilmente a las tareas personales, hábitos y necesidades individuales o proporcionar una variada gama de opciones para un amplio espectro de actividades que van desde el trabajo individual enfocado a través de la comunicación hasta los procesos en equipo.

Las condiciones físicas (iluminación, ventilación, acústica) y el mobiliario de los espacios debe cumplir con los requerimientos psicológicos, estándares ergonómicos y las disposiciones estatutarias, así como apoyar la actividad individual de manera óptima.

El uso del espacio debe contribuir a la transparencia de los procesos, promover la comunicación y la sinergia entre los empleados y departamentos con diferentes focos y contribuir a la calidad, rapidez y flexibilidad de los procesos.

En función de la adaptabilidad de las organizaciones a los nuevos paradigmas aparecerán tensiones laborales.

Las nuevas tecnologías de información y comunicación vinculadas a la cultura corporativa ayudarán a agravar o disolver dichas tensiones y a dar respuesta a los futuros espacios de trabajo.

Las organizaciones deben considerar la relación tecnología-espacio-personas para garantizar su competitividad y productividad.

El Estado del Arte analizado en este documento de tesis refleja sin lugar a dudas un vínculo entre el entorno de trabajo y las variaciones de productividad y bienestar de las personas.

Sin embargo, la aproximación que se realiza es generalmente cualitativa. Este tipo de análisis no permite obtener el necesario dato de cálculo del retorno de invertir en entornos enfocados a aumentar el bienestar de las personas.

La investigación a pie de campo que compone la primera parte de esta investigación, consistente en la visita y estudio de numerosos casos de estudio en diversos continentes, demuestra cómo existe un mayor porcentaje de entornos de oficinas que no apoyan el aumento de bienestar y productividad, y se concluye que en parte esto es debido a la ausencia de una herramienta que permita calcular dicho retorno de la inversión.

A partir de lo anterior, aparece el reto de cuantificar y objetivar el impacto en las variaciones de productividad y bienestar de las personas inducidas por las variables que componen los entornos de trabajo.

La presente investigación constituye una respuesta al mencionado reto, mediante la aportación de una herramienta que permitirá cuantificar el impacto de los entornos de trabajo en la variación de productividad y bienestar de las personas, lo cual constituye la principal aportación de esta Tesis.

Los casos de estudio en Japón y en Australia analizados desde una aproximación cualitativa en este capítulo sirven para aproximarse a las variables que despiertan un mayor interés desde el punto de vista de la mencionada relación tecnología-espacio-personas.

Como se ha indicado anteriormente en estas conclusiones, dichas variables se componen de aspectos tangibles, como las condiciones físicas, y de aspectos intangibles, relativos a procesos.

Este análisis servirá para identificar las variables cuyo impacto se cuantificará aplicando la herramienta, que se presenta en los siguientes capítulos de esta tesis, en tres casos de estudio de aproximación cuantitativa.

C.III. LA HERRAMIENTA

Este capítulo contiene la descripción detallada de la Herramienta de cuantificación del impacto de los entornos de trabajo en la variación de productividad y bienestar de las personas, la cual constituye la principal aportación de esta Tesis Doctoral. Se describe las cuatro fases de dicha Herramienta, dentro de las cuales se explica el concepto, los materiales empleados y los instrumentos y equipos necesarios.

1.FASE 0: KICK-OFF

1.1. Concepto.

Se ha diseñado una herramienta para cuantificar la influencia del entorno en el rendimiento intelectual, la creatividad y el bienestar, siguiendo una herramienta desarrollada en la Universidad de Keio, que se basa en la realización de experimentos piloto a través de pruebas fisiológicas, psicológicas, emocionales y culturales, en combinación con tareas de trabajo simuladas y bajo la monitorización de las condiciones ambientales.

Figura 1. Esquema de experiencia del usuario, base conceptual de la herramienta propuesta. Un experimento piloto simula la jornada diaria de una persona, como si de una película se tratara [1]. En esa película, analizamos fotograma por fotograma, compuesto por una capa de datos fisiológicos, capa psicológica, capa emocional y capa cultural [2]. Con un adecuado número de muestras, podemos combinar la información de las capas con resultados de tests relacionados con productividad y creatividad [3]. Si analizamos todas estas muestras, podemos identificar patrones y correlaciones [4]

1.2. Matriz RACI.

La Tabla I establece el reparto del total de tareas necesarias para el completo desarrollo de la herramienta propuesta. En esta Tabla se expresa cuatro grados de responsabilidad (responsable, aprobador, consultado, informado), que se asigna a tres tipos distintos de perfil:

- Sensei: director de laboratorio, nivel de profesor doctor.
- Sempai: director de proyecto, nivel de doctorando.
- Gakusei: colaborador, nivel de estudiante de último curso de grado o máster.

La nomenclatura presentada se corresponde al sistema de funcionamiento del laboratorio de investigación de la Universidad de Keio, en Japón, donde se llevan a cabo los dos primeros casos de estudio que se presentan en el siguiente capítulo de esta tesis.

En este contexto, la doctoranda tiene un perfil de Sempai, bajo la dirección de un perfil de Sensei. Las tareas desarrolladas se reflejan en la Tabla I, siendo las tareas propias de la doctoranda las siguientes:

- Establecimiento de la hipótesis de los casos de estudio presentes en esta tesis.
- Caracterización de las variables estudiadas: iluminación, madera y vegetación, tipo de espacio, formación a través de la gestión del cambio, realización de ejercicio físico y meditación en la jornada laboral.
- Diseño de los escenarios del experimento, creando espacio de control y espacios experimentales.
- Selección de las mediciones fisiológicas, psicológicas, emocionales y culturales a realizar, de acuerdo a la naturaleza del experimento.

- Liderazgo de talleres y sesiones previas necesarias para el entrenamiento de los participantes de los estudios.
- Supervisión de la toma de muestras fisiológicas y psicológicas, así como toma directa de algunas de ellas durante los días de ejecución del experimento, con apoyo de los perfiles Gakusei.
- Análisis de las muestras recogidas, recopilando los datos en una base de datos para la posterior aplicación de métodos estadísticos.
- Discusión de los resultados y establecimiento de las conclusiones, con supervisión del perfil Sensei.
- Desarrollar mediante el método de mejora continua la herramienta de medición que constituye la principal aportación de esta tesis.

Tabla I. Matriz de responsabilidades

		ROLES						
		SENSEI	SEMPAI	GAKUSEI 01	GAKUSEI 02	GAKUSEI 03	GAKUSEI 04	GAKUSEI 05
TAREAS	Reparto de roles	R	C	I	I	I	I	I
	Establecimiento hip. del experimento	R	R	I	I	I	I	I
	Proceso de selección de participantes	I	A	R	R	R	R	R
	Caracterización de variables	A	R	I	I	I	I	I
	Montaje de escenarios experimentales	I	R	R	R	R	R	R
	Selección de mediciones	A	R	I	I	I	I	I
	Calibrado de equipos y montaje	C	A	R	R	I	I	I
	Sesiones y talleres previos	C	R	C	I	I	I	I
TAREAS	Toma de muestras 5 días	I	R	R	R	R	R	R
	Procesado de datos Excel	I	R	R	I	I	I	I
	Aplicación métodos estadísticos SPSS	I	R	I	I	I	I	I
	Discusión de resultados	A	R	C	C	C	C	C
	Establecimiento de conclusiones	A	R	C	C	C	C	C

R	Responsable	A	Aprobador	C	Consultado	I	Informado

1.3. Hipótesis de cada experimento piloto.

Cada experimento piloto se diseña en base a las variables que se quieran medir, que se combinan formando escenarios. De esta forma, será posible analizar el impacto de las variables aisladas y el impacto conjunto de la combinación de distintas variables entre sí.

Dicho impacto se mide desde una aproximación holística de todo lo que afecta al bienestar de una persona, compuesto por cuatro partes: fisiológico, psicológico, cultural y emocional. Esta aproximación holística se sistematiza mediante la división en cuatro partes principales, que se establece a partir de la investigación llevada a cabo por la doctoranda, siendo una de las aportaciones que se presentan.

Las Tablas V, VI y VII de este capítulo describen las pruebas de estas cuatro partes que se realizan. En primer lugar, las mediciones fisiológicas se componen por indicadores biológicos del ser humano, que se relacionan con factores de bienestar. En segundo lugar, las mediciones psicológicas permiten cuantificar características humanas y objetivar procesos de evaluación relativos a inteligencia cognitiva. En tercer lugar, las mediciones emocionales permiten tener en cuenta características humanas no relativas a la inteligencia cognitiva, sino a la inteligencia emocional. Por último, las mediciones culturales permiten incluir características y hábitos aprendidos que afectan a los resultados.

El análisis de los tres casos de estudio cuantitativos demuestra que la combinación de estas cuatro partes permite la visión holística que se pretende, compuesta por todos los factores que afectan al bienestar de una persona.

La medición obtenida se traducirá en unos resultados de variaciones de siete indicadores: productividad, creatividad, motivación, confort, estrés, atención y sueño.

Figura 2. Esquema de establecimiento de hipótesis en cada experimento piloto

2. FASE 1: DISEÑO DEL EXPERIMENTO PILOTO

2.1. Selección de personas participantes.

El grupo de estudio se caracteriza de la siguiente manera: el mínimo es de dos personas por escenario, densidad de ocupación de mínimo catorce metros cuadrados por persona, hombres y/o mujeres, estudiantes universitarios, con un tipo de cuerpo estándar ($18.5 < \text{Índice de Masa Corporal (kg/m}^2) < 25.0$) y no fumadores.

Además, la caracterización de los participantes también se realiza según la teoría de la diversidad cognitiva. Este método se aplica siguiendo la referencia del autor Risner, que establece un método de aplicación intuitivo cuando equipara el entorno de oficina a un zoológico.

En este contexto, se establece que el 98% de las personas en entornos de trabajo se pueden circunscribir dentro de cuatro grandes grupos, representados por animales, como se ilustra en la Figura 3 [124].

La aplicación de esta teoría en la caracterización del grupo participante consigue obtener una muestra homogénea que no comprometa los resultados con particularidades.

Figura 3. Teoría de la diversidad cognitiva equiparando los espacios de oficinas con un zoológico. Autor: Nigel Risner

En cada experiencia piloto, los sujetos realizan una serie de tareas simulando trabajo de oficina, con tres bloques de tareas establecidas por la mañana y tres por la tarde. Durante el trabajo de simulación, se realiza trabajo de procesamiento de información y trabajo de creación de conocimiento.

Estos estudios se llevan a cabo bajo el protocolo aprobado por el comité de investigación en bioética de la Facultad de Ciencias y Tecnología de la Universidad de Keio (nº 28-19).

Asimismo, se utiliza la versión española del Cuestionario de Evaluación de Síntomas (SA-45), de Davison, MK, Bershadsky, B., Bieber, J., Silversmith, D., Maruish, ME, y Kane. RL, 1997, la cual sirve como herramienta de detección de cualquier posible trastorno psicopatológico. Consta de 45 ítems derivados del SCL-90, y nueve escalas de cinco ítems cada una que evalúan las mismas dimensiones que el SCL-90 (depresión, hostilidad, sensibilidad interpersonal, somatización, ansiedad, psicotismo, obsesión-compulsión, ansiedad fóbica e ideación paranoide) [133], [26].

Tabla II. Factores a considerar en la selección de personas participantes en los experimentos piloto

Nº	FACTOR	CARACTERIZACIÓN MEDIANTE ENTREVISTA
01	NÚMERO DE PARTICIPANTES	Mínimo de 2 personas por escenario Densidad de ocupación: mínimo 14 m ² por persona
02	MASA CORPORAL	Tipo estándar ($18.5 < \text{Índice de Masa Corporal} < 25.0$)
03	ARROPAMIENTO	Seleccionado por cada sujeto. Control de la temperatura corporal
04	EDAD	18-21 años
05	NIVEL CULTURAL	Estudiantes universitarios
06	DIVERSIDAD COGNITIVA	Grupo homogéneo de acuerdo a la teoría de diversidad cognitiva (Figura 3)
07	TABAQUISMO	No fumadores
08	ESTUDIO PSICO-PATOLÓGICO	Symptom Assessment-45 Questionnaire (SA-45)

2.2. Caracterización de variables.

En los casos de estudio presentados en esta tesis aparecen seis variables distintas, cuya caracterización se realiza mediante la determinación de las cualidades descritas en la Tabla III.

Tabla III. Caracterización de las variables utilizadas en los Casos de Estudio

VARIABLE	CARACTERÍSTICAS
VEGETACIÓN	0,2 plantas / m ²
	Plantas autóctonas de la región donde se lleve a cabo el estudio
	Selección estudio NASA
ILUMINACIÓN	Patente de tubo solar horizontal definido en el Caso de Estudio 1
MADERA	Madera autóctona de la región donde se lleve a cabo el estudio
	Superficie del 45% de la habitación
	Clasificación de color: claro
	Madera natural, no barnizada
	Paneles de madera maciza
TIPO DE ESPACIO OFICINA	Definición en planta de la superficie utilizada, con una densidad mínima de 14 m ² por persona
FORMACIÓN A TRAVÉS DE LA GESTION DEL CAMBIO	Al tratarse de variables intangibles, se explica las dinámicas seguidas y la programación en el caso de estudio
EJERCICIO FISICO Y MEDITACIÓN	

2.3. Creación de escenario de control y escenarios experimentales.

Teniendo en cuenta los requerimientos de selección de participantes y la hipótesis de los experimentos piloto, la Tabla IV muestra la configuración del experimento piloto combinando tres escenarios, que estudian dos variables aisladas y la combinación de varias, siendo la configuración de los escenarios la siguiente:

- Escenario 1: Variable 1 aislada
- Escenario 2: Variable 2 aislada
- Escenario 3: Variable 1 más variable 2

En función del número de variables, se creará un mayor o menos número de escenarios.

Tabla IV. Configuración de escenarios con dos variables.

		DÍA 1	DÍA 2	DÍA 3	DÍA 4	DÍA 5
GRUPO A	Sujeto 1	ESCENARIO 1	ESCENARIO 1	ESCENARIO 3	ESCENARIO 3	ESCENARIO 3
	Sujeto 2					
	Sujeto 3					
	Sujeto 4					
GRUPO B	Sujeto 5	ESCENARIO 3	ESCENARIO 3	ESCENARIO 3	ESCENARIO 2	ESCENARIO 1
	Sujeto 6					
	Sujeto 7					
	Sujeto 8					

2.4. Selección de mediciones a realizar.

Se diseña una experiencia piloto con evaluación subjetiva y objetiva, para cuantificar el desempeño de los sujetos participantes. La combinación de ambas proporciona una visión holística de la percepción humana, como se representa en la Figura 4.

Para la evaluación objetiva, se miden parámetros físicos y fisiológicos, a partir de grupos experimentales y un grupo de control, antes y después de la aparición de variables.

Los resultados son analizados para determinar cualquier diferencia estadísticamente significativa entre los grupos y entre los sujetos antes y después de la prueba.

Además, se realizan pruebas diarias de condiciones ambientales. Las tablas V, VII, VIII, IX y X resumen todos los ítems medidos.

Figura 4. Esquema de mediciones que se realizan en cada experimento piloto, y que conforman la herramienta presentada

La información fisiológica, el valor de actividad simpática del sistema nervioso autónomo, la frecuencia cardíaca, el valor de actividad de la amilasa salival, la presión arterial, la temperatura de la membrana timpánica, la cantidad de actividad, etc. se miden en los intervalos de tiempo definidos en la Tabla V.

Los equipos necesarios para estas mediciones fisiológicas, se definen en la tabla VI.

Tabla V. Mediciones fisiológicas

Indicador medido (QUÉ)	Método de medición (CÓMO)	Momento de medición (CUÁNDO)
Tensión arterial	Tensiómetro de muñeca	Antes y después de cada sesión de trabajo
Ritmo cardíaco	Electrodos	Durante toda la jornada laboral
Temperatura corporal	Termómetro de frente u oído	Antes y después de cada sesión de trabajo
Actividad física	Podómetro	Durante todo el día, todos los días de ejecución del experimento
Calidad del sueño	Medidor de sueño	Cada noche desde dos semanas antes de comenzar el experimento y hasta dos semanas después
Enzima amilasa	Análisis de saliva	Antes y después de cada sesión de trabajo
Cortisol		Cuatro veces al día
DHEA		
Ondas cerebrales	Medidor de ondas cerebrales	Durante todo el tiempo de cada sesión de trabajo
Estrógenos (sólo mujeres)	Termómetro sublingual	Dos veces: un mes antes del experimento y un mes después

Tabla VI. Equipos de medición fisiológica

Indicador medido	Método de medición	Instrumento de medida
Ritmo cardíaco	Electrodos adheridos en dos puntos del torso, conectados a un receptor portátil	
Concentración de enzima amilasa en saliva	Una tira de celulosa se sitúa bajo la lengua y después se introduce en el monitor de medición	
Tensión arterial	Pulsómetro de brazo	
Indicador medido	Método de medición	Instrumento de medida
Ondas cerebrales	Dispositivo que se sitúa en la cabeza	
Temperatura corporal	La parte de medición se introduce en el oído	
Actividad física	Se sitúa en la cintura con un clip y mide el número de pasos y el tipo de actividad física a través de un sensor de tres nodos	
Indicador medido	Método de medición	Instrumento de medida
Concentración de estrógenos en saliva (sólo mujeres)	Una única medición	
Temperatura sublingual (sólo mujeres)	Una medición una semana antes del experimento piloto, y una medición una semana después	
Calidad del sueño	En casa, mientras se duerme	

Los participantes son evaluados por la versión española de la Escala de Esfuerzos Percibidos (PSS), por Cohen, S., Kamarck, T., & Mermelstein, R. en 1983, demostrando una fiabilidad adecuada (consistencia interna y prueba-retest), validez (concurrente) y sensibilidad [25], [50].

Consiste en catorce ítems con un formato de respuesta de una escala de cinco puntos (0 = nunca, 1 = casi nunca, 2 = ocasionalmente, 3 = a menudo, 4 = muy a menudo), que evalúan la frecuencia con la que el participante tuvo pensamientos y sentimientos estresantes durante el último mes.

Los hábitos de sueño son evaluados a través del Cuestionario de Hábitos de Sueño (CHAS) desarrollado por el Dr. Díaz Ramiro y el Dr. Rubio Valdehita en 2013 [33].

Este cuestionario consta de 30 ítems que evalúan los hábitos de sueño en el momento actual del participante a través de una escala *likert* (donde uno representa que el sujeto está en "total desacuerdo" con la afirmación y cinco en "total acuerdo").

Evalúa tres dimensiones: calidad del sueño, estabilidad en los hábitos de sueño y somnolencia diurna. Sus índices de validez y fiabilidad convergentes son aceptables.

La versión corta del cuestionario IPAQ, pregunta sobre tres tipos de actividades. Los tipos específicos de actividad son "caminar", "actividades de intensidad moderada" y "actividades de intensidad vigorosa". Los ítems de la versión corta están estructurados para proporcionar resultados separados para los tres tipos de actividades de "caminar", "actividades de intensidad moderada" y "actividades de intensidad vigorosa" [130].

La obtención del resultado para la versión corta requiere la adición de la duración (en minutos) y la frecuencia (días) de estos tres tipos.

El cuestionario EVEA fue construido como un instrumento para medir los estados de ánimo transitorios en estudios que utilizan procedimientos de inducción del estado de ánimo [134].

EVEA consta de dieciséis ítems, cada uno compuesto por una escala gráfica de once puntos (de 0 a 10), flanqueada por las palabras "nada" (0) y "mucho" (10), que presenta en su margen izquierdo una breve afirmación que describe un estado de ánimo. Las dieciséis frases tienen la misma construcción; todas comienzan con las palabras "I feel" y continúan con un adjetivo que representa un estado de ánimo (es decir, "I feel sad", "I feel happy").

EVEA tiene como objetivo evaluar cuatro estados de ánimo: ansiedad, ira-hostilidad, tristeza-depresión y alegría. Cada estado de ánimo está representado por cuatro elementos con diferentes adjetivos que definen una subescala, y todos los elementos dentro de cada subescala están formulados en la misma dirección.

Los sujetos rellenaron un cuestionario SAP para analizar la influencia del medio ambiente en el edificio, tanto la percepción del confort como el rendimiento intelectual.

Esta encuesta fue estudiada por la Asociación Japonesa de Construcción Sostenible, el Instituto Japonés de Arquitectura y la Sociedad de Ingeniería de Aire Acondicionado y Saneamiento [78] y en el Caso de Estudio III de esta Tesis Doctoral se utiliza la versión adaptada, como aportación de esta investigación.

El grado de satisfacción con el ambiente interior se evaluó en una escala de seis grados: confort térmico, luz, ruido, calidad del aire y ambiente espacial tanto del lugar de trabajo como del área de descanso. [136], [143], [149], [184].

El Comité de Salud Ocupacional de Japón propuso el método de cuestionario Jikaku-sho Shirabe en 2002 [154]. Este cuestionario consta de 25 ítems de síntomas de fatiga subjetiva.

También se estudiaron la condición física, la fatiga, la somnolencia y la eficiencia subjetiva del trabajo antes y después del trabajo [78], [143], [148], [149], [150], [154], [170], [184]. Por lo tanto, la investigación de los síntomas subjetivos también se utilizó para evaluar la percepción de la fatiga.

Aunque abundan las técnicas de evaluación de la carga de trabajo, las calificaciones subjetivas son el método más utilizado y son los criterios con los que se comparan otras medidas.

En la mayoría de los entornos operativos, uno de los problemas encontrados con el uso de escalas de calificación subjetivas ha sido el gran grado de variabilidad. [60], [61], [108].

NASA TLX es una técnica de clasificación por la cual se reduce la variabilidad. NASA TLX, que es multidimensional, proporciona un método a través del cual se pueden identificar y considerar fuentes específicas de carga de trabajo relevantes para una tarea dada al calcular una calificación general de la carga de trabajo.

Combina información sobre estos factores, reduciendo así algunas fuentes de variabilidad entre temas que son experimentalmente irrelevantes en el piloto, y enfatizando las contribuciones de otras fuentes de variabilidad que son experimentalmente relevantes en el piloto [34], [60], [61], [108].

Tabla VII. Mediciones Psicológicas, emocionales y culturales

Indicador medido (QUÉ)	Método de medición (CÓMO)	Momento de medición (CUÁNDO)
Hábitos de sueño	Test CHAS	Al inicio y al final del experimento
Hábitos de ejercicio físico	Cuestionario Internacional de Actividad Física	
Carga subjetiva de trabajo	Test NASA TLX	Antes y después de cada sesión de trabajo
Estrés	Test PSS	Al inicio y al final del experimento
Estado de ánimo	Test EVEA	Antes y después de cada sesión de trabajo
Bienestar emocional y físico	Cuestionario Jikuko-sho	
Percepción del Espacio	Cuestionario modificado SAP	

La medición de la Productividad se relaciona con la capacidad cognitiva, tal como muestra la Tabla VIII. Se evaluaron cuatro habilidades cognitivas genéricas: memoria, concentración, razonamiento y repetición.

Tabla VIII. Mediciones de Productividad

Indicador medido (QUÉ)	Método de medición (CÓMO)	Momento de medición
Capacidad cognitiva relacionada con memoria	Sumas	Dos veces al día, en sesión de mañana y tarde
Capacidad cognitiva relacionada con atención	Test de Stroop	
Capacidad cognitiva relacionada con razonamiento	Sudoku	
Capacidad cognitiva relacionada con repetición	Mecanografía	

Como se observa en la Figura 4, usando el software de mecanografía "C-Type", los sujetos escriben un texto en inglés estadounidense, para medir la eficiencia de un trabajo sencillo.

Cuando se completa la entrada de uno de los archivos de texto, la velocidad de escritura, el número de bateo y el promedio de bateo se miden automáticamente.

La Figura 5 muestra un ejemplo de la tarea de suma, que se realiza con un software desarrollado en la Universidad de Keio.

Figura 4. Interfaz de la tarea denominada “mecanografía”

Figura 5. Ejemplo de la tarea denominada “sumas”

En 1935, el hijo de un granjero llamado John Ridley Stroop, fue el primero en publicar en inglés la versión actual de esta tarea cognitiva. Desarrollada como parte de su disertación en George Peabody College, su tarea se convirtió en la base del Test de Stroop, que a la fecha sigue siendo una evaluación neuropsicológica ampliamente utilizada. [54].

Dado que para la mayoría de las personas la respuesta automática es leer una palabra, el Test de Stroop es una prueba clásica de inhibición de respuesta.

Esta habilidad cognitiva implica responder rápidamente mientras se evitan los impulsos incorrectos que pueden interferir en la consecución de tareas impulsadas por metas.

La inhibición de respuesta se asocia con la función ejecutiva del cerebro y los estudios de imagen cerebral han mostrado que realizar el Test de Stroop activa áreas cerebrales que participan en la función ejecutiva, como la corteza dorso lateral prefrontal. [54].

El Test de Stroop también pone a prueba la atención selectiva; es decir, la capacidad de elegir los estímulos en los que te vas a concentrar y los que vas a ignorar. La flexibilidad mental que se requiere para alternar entre múltiples estímulos es esencial: sin una buena atención selectiva, puede ser muy fácil cometer errores. [54].

El Test de Stroop ha sobrevivido a su creador. Citado miles de veces, su trabajo original es uno de los estudios más famosos de la psicología experimental. Se siguen usando versiones de su prueba en la investigación. [54]. La Figura 6 muestra un ejemplo del Test de Stroop.

Figura 6. Ejemplo de test de Stroop

			2	6				
	3				9	7	5	
2				5	4			
5		8	4			6	9	
	4	2			8	5		7
			3	2				5
	9	6	5				2	
				8	6			

Figura 7. Ejemplo de la tarea de trabajo simulado denominada “sudoku”

Otra alternativa es la utilización de las pruebas del sitio web público de Cambridge Brain Sciences (CBS), basadas en paradigmas clásicos de la literatura de psicología cognitiva. (Figura 8)

Para la capacidad de memoria, la tarea *Digit Span* prueba la memoria verbal de los sujetos recordando una secuencia de números que aparecen en la pantalla uno tras otro; la tarea *Spatial Span* prueba la memoria visual-espacial de los sujetos recordando una secuencia de cuadros parpadeantes que aparecen en la pantalla uno tras otro.

En cuanto a la capacidad de concentración, la prueba de rotación se utiliza para medir las habilidades de rotación mental de los sujetos, mientras que la prueba de coincidencia de características combina el procesamiento de la atención de los sujetos mediante la comparación de las características de varias imágenes de diferentes maneras y la indicación de si el contenido es idéntico.

En las habilidades de razonamiento, la tarea de *Odd One Out* requiere que los participantes determinen cuál de los nueve patrones es el extraño; la tarea de Razonamiento Gramatical requiere que los participantes indiquen si una frase describe correctamente un par de objetos que se muestran en el centro de la pantalla.

Las descripciones detalladas de las ocho pruebas de rendimiento cognitivo se pueden encontrar en la Información suplementaria de Schweizer [137].

Figura 8. Esquema de tareas desarrolladas por el Cambridge Brain Institute

En la Tarea del Mapa Mental, las palabras están asociadas con una palabra, como muestra la Figura 9. Necesitamos tantas respuestas como sea posible en el tiempo, para evaluar la creación de conocimiento. Esta tarea se realiza en un papel.

Dado que el trabajo creativo puede ser medido a lo largo de los espectros de forma y contenido, la Taxonomía del Pensamiento de la Creatividad ofrece una progresión desde la imitación hasta la creación original medida en términos de forma y contenido, como se muestra en la Figura 10.

Tabla IX. Mediciones de Creatividad

Indicador medido (QUÉ)	Método de medición (CÓMO)	Momento de medición
Cantidad de ideas generadas	Mapa Mental	Dos veces al día, en sesión de mañana y tarde
Cantidad y calidad de ideas generadas	Método de Taxonomía del Pensamiento Creativo	

Figura 9. Ejemplo de Mapa mental

Figura 10. Método de Taxonomía del Pensamiento Creativo

A lo largo del experimento piloto, de acuerdo con la norma ASHRAE 55 [3], la temperatura interior y exterior, la humedad, la velocidad del aire, la concentración de CO₂, la iluminación y el nivel de ruido son medidos por dos estaciones de medición ambiental por cada escenario establecido.

De acuerdo con la norma ASHRAE 55, la renovación de aire durante las pruebas es de 0,3 litros por segundo por metro cúbico. Los elementos medidos se presentan en la Tabla IX y los equipos que componen las estaciones de medición ambiental son descritos en la Tabla XI.

Tabla X. Mediciones ambientales

Indicador medido (QUÉ)	Método de medición (CÓMO)	Momento de medición (CUÁNDO)
1.1m Temperatura [°C]	Estación de medición ambiental	Continuo durante todos los días
Humedad [%]		
Flujo de aire interior [m/s]		
Temperatura general [°C]		
Concentración de CO2 [ppm]		
Ruido [dB]	Sonómetro	Cada 15 minutos durante las sesiones de trabajo
Iluminación en el plano horizontal [lx]	Luxómetro	
Iluminación en el plano vertical [lx]		

Tabla XI. Equipos de medición ambiental

Indicador medido	Método de medición	Instrumento de medida
Iluminación en la superficie de trabajo (lx), iluminación vertical (lx), temperatura de color (K)	Luxómetro, medidor de temperatura de color	
Distribución de brillo (cd/m2)	Medidor de distribución de brillo	
Temperatura del aire (°C), Humedad relativa (%)	Medidor automático de temperatura y humedad	
Termografía	Cámara de infrarrojos	

Indicador medido	Método de medición	Instrumento de medida
Temperatura radiante (°C)	Globo	
Flujo de aire interior (m/s)	Anemómetro	
Concentración de CO2 (ppm)	Sistema de calidad del aire interior	
Sonido (dB)	Sonómetro	

Indicador medido	Método de medición	Instrumento de medida
Temperatura exterior, humedad, viento	BEMS	
Nivel de iluminación del cielo	Luxómetro	
Huecos, ocupación, envolvente, iluminación general del área de trabajo	Visual	

2.5. Definición de programación temporal.

En las Figuras 11 y 12 se muestra el programa diario típico del experimento piloto. Los sujetos se sitúan en el ambiente simulado a las 9:00 a.m. En primer lugar, responden a un cuestionario sobre las actividades del día anterior. A continuación, se inicia una sesión de 60 minutos, con una medición fisiológica, un cuestionario y un trabajo simulado con dos tareas diferentes, cada una de 25 minutos de duración.

Antes y después de la experiencia piloto, los sujetos disfrutaban de tiempo libre. Sin embargo, el ejercicio vigoroso o el consumo de alcohol están prohibidos.

Figura 11. Programación tipo de los experimentos piloto

Se ha demostrado que el rendimiento disminuye a medida que la tarea llega a su fin. La Tarea 3 se añade con el objetivo de no comprometer los resultados de las Tareas 1 y 2, y no se consideraron los resultados de la Tarea 3, eliminando así el "efecto tiempo final" [35].

Figura 12. Ejemplo de programación diaria

3. FASE 2: EJECUCIÓN DE EXPERIMENTO PILOTO

Después de la Fase 1 de diseño del experimento piloto, se procede a la Fase 2, correspondiente a la ejecución del experimento piloto. Esta Fase consta de tres actividades:

- Calibrado de equipos de medición, definidos en el apartado 2 de este capítulo.
- Formación previa y entrenamiento sobre las tareas de trabajo simulado
- La toma de muestras fisiológicas, psicológicas, emocionales, culturales, de pruebas de productividad y creatividad y medición de condiciones ambientales. Todo ello conforma la ejecución en sí del experimento piloto.

El responsable de cada tarea se definió en la Fase 1, como indica la Tabla I de este capítulo.

La programación de estas tres partes se muestra en la Figura 13, mientras que la programación detallada de cada día de ejecución se muestra en las Figuras 11 y 12.

Figura 13. Programación de la Fase 2 de Ejecución del Experimento Piloto

4. FASE 3: ANÁLISIS DE DATOS Y CONCLUSIONES

4.1. Procesado de datos y análisis.

Para eliminar las diferencias individuales de capacidad, se normalizan y analizan los resultados obtenidos. Además, se eliminan los resultados de la sesión de entrenamiento del primer día, teniendo en cuenta el efecto de la inexperiencia [119].

4.2. Aplicación de métodos estadísticos.

En el análisis de la relación entre variables tangibles e intangibles, se realiza un estudio estadístico mediante el método ANOVA unidireccional.

Primero, los resultados se identifican fuera de la distribución normal. Se detectan los resultados fuera de la distribución normal y los resultados extremos. Se identifican los sujetos que presentan resultados anormales de productividad, eliminando las muestras extremas del análisis [87].

Después de eliminar los valores extremos, y dado que se trata de un experimento piloto esto hace que se reduzca la muestra, se procede a realizar la prueba Shapiro-Wilk para confirmar que las muestras tienen una distribución normal [84].

La correlación entre variables tangibles se mide mediante el método estadístico denominado coeficiente de correlación o coeficiente de Pearson, que representa la fuerza de la supuesta asociación lineal entre las variables en cuestión [100].

El coeficiente de correlación de Pearson representa la fuerza de la supuesta asociación lineal entre las variables en cuestión. Es una cantidad sin dimensiones que toma un valor en el rango de -1 a +1.

Un coeficiente de correlación de cero indica que no existe una relación lineal entre dos variables continuas y un coeficiente de correlación de -1 o +1 indica una relación lineal perfecta. La fuerza de la relación puede estar entre -1 y +1.

Cuanto más fuerte es la correlación, más se acerca el coeficiente de correlación a ± 1 . Si el coeficiente es un número positivo, las variables están directamente relacionadas.

Por otro lado, si un coeficiente es un número negativo, las variables están inversamente relacionadas [100]. El coeficiente de correlación de Pearson se indica mediante "r" en la Fórmula 1.

Fórmula 1. Coeficiente de correlación o de Pearson

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{[\sum_{i=1}^n (x_i - \bar{x})^2][\sum_{i=1}^n (y_i - \bar{y})^2]}}$$

Para evaluar la significancia estadística, se examina el valor "p" de la prueba. Si el valor "p" está por debajo de un nivel de significancia de 0.05 se establece que la diferencia es estadísticamente significativa y se rechaza la hipótesis nula de la prueba.

4.3. Establecimiento de resultados, discusión y conclusiones.

Después de identificar la significancia estadística de las mediciones realizadas, mediante los métodos descritos en el anterior apartado, se procede a estudiar las variaciones de las relaciones que presentaron dicha significancia. La Figura 14 muestra un flujograma del proceso completo de análisis de Fase 3.

Figura 14. Flujograma de análisis de resultados de los experimentos piloto

C.IV. CASE STUDIES

This chapter explains in detail the case studies carried out between 2016 and 2017 that serve to check the validity of the proposed tool.

1. CASE STUDY 1

1.1. Abstract.

A scheduled pilot experiment, as a small-scale version done in preparation for a major study, has been conducted to test the tool that quantifies the impact of biophilic design features on performance and well-being, to evaluate the influence of variables such as greenery and daylight on improving workplace performance, and look at biophilic design knowledge in greater depth.

The role of natural indoor environments - understood as spaces within buildings provided with elements of nature - has received relatively little attention, compared to the number of studies evaluating occupant impact related to other characteristics of indoor environments derived from mechanical and electrical systems such as thermal factors, noise and vibration, ergonomics and office design.

The present study is one of the first studies evaluating and measuring the combination of greenery and daylight into a biophilic design proposal.

The results highlight an improvement in well-being, performance, creativity and health by introducing daylight and greenery into workplace design such as biophilic design features. The tool developed and tested in this pilot experiment opens a way to improve measured workplace performance to a much greater extent in contrast to the existing practice.

1.2. Introduction.

Numerous studies endorsed by the scientific community, affirm that biophilic design, defined as a response to the inherent need of human beings to be in contact with nature [176], in the workplace improves productivity and user well-being [65], [66].

The first challenge applied to architecture is to increase contact with nature in spaces through an optimal design. *If you cannot measure it, you cannot improve it* [175], so the second challenge that arises is how to objectify and quantify rigorously the features that improve productivity and well-being in biophilic-design spaces.

A tool has been designed to quantify the influence of the use of biophilic design on intellectual performance, creativity, and well-being, following a methodology developed in Keio University, tested by a pilot experiment carried out through physiological tests, psychological tests, and simulated work tasks.

Previous studies have shown that the relationship between indoor building design and wellbeing of occupants are complex [Bluyssen et al., 1995]. There are many indoor stressors, such as excessive thermal factors, lighting aspects, moisture, noise and vibration, radiation, chemical compounds, and particulates fluctuations that can cause their effects additively or through complex interactions.

It has been shown that exposure to these stressors can cause both short-term and long-term effects. In the workplace, a whole range of effects has been associated with these stressors such as Sick Building Syndrome (SBS), building-related illnesses and productivity loss.

The premise that the office environment can influence people in ways that may reduce or improve their productivity is well established [23], [79], [92], [103], [114], [126], [139], [165].

Numerous studies have shown that indoor air quality [140], [151], [171], [181], thermal conditions [49], [59], [117], [140], lighting [15], [165], noise [122], [131], [153], office design [17], [62], and ergonomics [7] can influence people's cognitive abilities, their health, their attitudes, and their productivity.

Previous research by Professor Ikaga's laboratory, amongst others, have identified biophilic design features as a key driver of performance and well-being in the workplace.

Wooden interiors, temperature, and promotion of physical activity have independent impacts on cognitive function, performance, health, and well-being. [2], [155], [111], [160], [107], [109], [110], [161], [112], [4], [113].

Although previous studies have shown associations between indoor stressors and comfort, health and productivity in an office environment, relevant relations between lighting and greenery combination as biophilic design and effects have been difficult to establish.

Lighting and greenery are selected in the pilot experiment because they are features included in the WELL certification within the category of Biophilia [71] and because in the State of the Art is possible to find few examples of pilot experiments that combine these two characteristics [16].

In this Case Study, the term *pilot experiment* is used as a small-scale version done in preparation for the major study [120]. One of the advantages of conducting a pilot experiment is that it might provide an advanced warning about where the main research project might fail, where research protocols may not be followed, or whether the proposed methods are inappropriate or too complicated. Pilot experiments are a crucial element of good study design.

Conducting a pilot experiment does not guarantee success in the main study, but it does increase the likelihood. The pilot experiment fulfills a range of important functions and can provide valuable insights for other researchers [163].

Performance is defined as what people can produce with the least effort [128]. Sutermeister simply defines performance as output per employee hour, quality considered [152]. Dorgan defines performance as the increased functional and organizational performance, including quality [36].

An increase in performance is expressed as a directly quantifiable reduction in absenteeism. However, the improvement in performance can also be the result of an increase in the quantity and the quality of production during the period that employees are actively working [126].

The United Nations predicts that by 2030, 60% of the world's population will live in urban environments [1]. It is therefore imperative that we consider how the connection between people residing in cities and nature can be maintained, and what are the most impact parameters in human's well-being, health, and performance. Relevant authors have stated that the answer to this challenge is biophilic design [18].

The American biologist and entomologist, Edward O. Wilson, was the first to formulate the hypothesis that contact with nature is essential for the psychological development of people. His theory says that for millions of years our species was related to its wild environment, created a kind of dependency, an overwhelming emotional need to be in contact with other living beings. This inherent need was called Biophilia [176], [177].

Between 1993 and 1995, the scientists Roger S. Ulrich and Stephen Kellert specified the final approach to the term Biophilia defining it as "the innate human affinity for nature" [81] and established the basis of what application of this sensitivity to design and architecture will be [82].

The incorporation of the concept of biophilia means bringing nature closer to the urban environment, evoking the double essence of the human being: social and natural [18].

The challenge of biophilic design is to address the shortcomings of contemporary architecture in buildings, landscapes, and the interior, initiating a new framework for the beneficial experience of nature in the urban environment. [83].

A report on human space in Europe, the Middle East and Africa, published in 2014 [180], specifically examined the impact of biophilic design in that geographic area and served as the basis for a global research project.

This research quantifies the benefits of biophilic design in workspaces collecting data from 16 countries around the world, in today's urban environment, people are increasingly isolated from the beneficial experience of natural systems and processes. By imitating these natural environments in workplaces, they are provided with positive emotional experiences. [18].

Research carried out among workers to find out which elements are most valued in their work environment, shows that natural light is the most sought-after element within the workplace. Similarly, indoor plants and vivid colours are ranked in the top five [65], [66], [80].

At work, when we focus our attention on a demanding task, the factors in our environment that interrupt us can lead to mental fatigue. However, workplaces that incorporate nature provide calmer adjustments that facilitate easier attention and can restore our mental capacity.

This is known as the Theory of Restoration of Attention, which postulates that seeing and experiencing nature involves a different part of the brain that is used in the high-attention approach [44].

There is a continuous and dynamic interaction between people and their surroundings that produces physiological and psychological strain on the person, which consequently lead to changes in health, well-being and performance [116], [23], [89].

There are many factors among others such as level of education, skills, age, gender, circadian cycle, emotional states and response bias that should be considered when investigating the relationship between indoor architecture and human performance [116], [23], [89]. Consequently, the accurate selection of experimental subjects was a part of the tool tested in this Case Study.

Accuracy and speed are the two distinct aspects of human performance. Accuracy is a measure of the quality of behavior. Measures of accuracy include number correct, percent correct, and the probability of correct detections [51].

Laboratory studies typically assessed work performance by having subjects performing cognitive tasks that simulated aspects of actual work and by subsequent evaluation of the speed (response time) and accuracy (percent errors). For example, subjects typed per unit time, number of completed addition or multiplication units per unit time, etcetera. [181], [182], [171], [172], [11], [178], [88], [89].

In this research, a holistic approach to measure human performance and well-being was proposed, and the tool was checked experimentally with a pilot experiment.

1.3. Objectives.

The improvement in well-being and performance in the workplace are economic and social critical factors since the loss of productivity for companies means a cost of up to US\$ 550,000 million per year [145].

The purpose of this pilot experiment is to test the proposed tool to quantify objective variables and to assess how much greenery and daylight influence users' perceptions, and its effect on performance, creativity, well-being, and health.

1.4. The Tool.

A pilot experiment was designed with both subjective and objective evaluation, to quantify the subjects' performance. User perceptions were examined using the NASA TLX questionnaire, Subjective Assessment of Workplace Performance questionnaire, and the Jikuko-sho questionnaire. The combination of these methods provides a holistic view of the subjective human perception.

For the objective assessment, we measured the physical and physiological parameters, from two experimental pilot groups and a control group, before and after the installation of greenery and daylight.

The results were analyzed to determine any statistically significant differences between the three groups and between the pre- and post-test subjects.

Furthermore, daily tests were carried out for temperature, relative humidity, CO₂, and light. Table I summarizes all the items measured.

Table I: Pilot experiment measurement items.

	Item	Method	Time
Physiological measurements	Autonomic nerves	Heart rate	Continuous
	Activity level	Activity meter	
	Sleeping latency and efficiency	Sleep gauge	At home
	Saliva amylase concentration	Saliva amylase activity monitor	
Psychological measurements	Fatigue - drowsiness	Questionnaires	Before and after work
	Indoor environmental satisfaction		
	Subjective working efficiency		
	Subjective workload		
	Objective work efficiency: typing (information processing work), mind map (knowledge creation work)	Tasks	During work
Environmental measurements	Light (lx)	Environmental measurement station	1-minute interval
	Temperature (°C)		
	HR (%)		
	Radiation temperature (°C)		30-minute interval
	Wind speed (m/s)		
	CO ₂ concentration (ppm)		
	Noise (dB)		

1.5. Pilot experiment assessment.

The pilot experiment with subjects was carried out in a laboratory environment at the Taisei Company (Fig. 2) for a total of 5 days. The study group was characterized as follows: subjects were eight males, college students, with a standard body type ($18.5 < \text{Body Mass Index (kg/m}^2) < 25.0$) and non-smokers.

In this pilot experiment, the subjects carried out a series of tasks simulating office work, with three tasks set in the morning, and three in the afternoon (Fig. 2). During simulation work, text typing was done as information processing work and the mind map as knowledge creation work.

This study was carried out under the protocol approved by the bioethics research committee of the Faculty of Science and Technology, Keio University (No.28-19).

Figure 1a. Interior of the experimental pilot location.

Figure 1b. Exterior of the experimental pilot location.

The typical daily pilot experimental schedule is shown in Figure 2. The subjects were placed in the simulated environment at 9:00 a.m. Firstly, they answered a questionnaire about the activities of their previous day.

After that, a 60-minute session started, with a physiological measurement, questionnaire and simulated work with two different tasks, each one lasting 25 minutes.

Before and after the pilot experiment, the subjects had some free time. However, strenuous exercise or drinking alcohol were forbidden. Table II shows the pilot experiment setup combining the three Scenarios. Each Scenario combines greenery and daylight as variables.

It has been demonstrated that performance decreases as the task comes to an end. Task Set three was added with the aim of not compromising the results of Task Sets one and two, and the results of Task Set three were not considered, thus eliminating the "end time effect" [35].

Figure 2. Pilot experiment schedule.

Table II: Pilot experiment setup combining the three scenarios. Each Scenario combines greenery and daylight as variables.

		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
GROUP A	Subject 1	SCENARIO	SCENARIO			
	Subject 2	1: no	1: no	SCENARIO	SCENARIO	SCENARIO
	Subject 3	daylight, no	daylight, no	3: daylight, greenery	3: daylight, greenery	3: daylight, greenery
	Subject 4	greenery	greenery			
GROUP B	Subject 5					SCENARIO
	Subject 6	SCENARIO	SCENARIO	SCENARIO	SCENARIO	1: no
	Subject 7	3: daylight, greenery	3: daylight, greenery	3: daylight, greenery	2: no daylight, greenery	daylight, no
	Subject 8					greenery

Scenario 1 corresponds to the control group. In Scenario 2 and Scenario 3, four units of Dracaena Lemon Lime, four units of Aloe Vera, and four units of Sansevieria Trifasciata (Snake plant) were placed in the workplace. The plants were selected according to the classification made by the NASA study of plants [179].

Table III summarizes the main characteristics of the selected plants and Figure 3 shows the pilot experiment layout with the position of the greenery.

Table III: Selected greenery

Name	Dracaena Lemon Lime	Sansevieria Trifasciata	Aloe Vera
Size	Large	Large	Small
Contaminants it eliminates	Trichloroethylene, Formaldehyde, Xylene	Trichloroethylene, Formaldehyde, Benzene, Ammonia	Formaldehyde, Benzene
Picture			

Figure 3. Layout of the pilot experiment location.

The workplace was divided into two zones of 70 square meters each. In turn, each zone was divided into two symmetrical longitudinal halves: in one the necessary equipment was installed (Figure 4, blue marks), and in the other, the subjects of the pilot experiment were located with an occupancy ratio of 8.75 square meters per person.

This ratio exceeds the minimum recommended of 2 square meters per employee. Both areas of 70 square meters were equipped with plants when the corresponding Case Study required it, with a ratio of 0.2 plants per square meter in the area occupied by the subjects.

Regarding the resting time area, two Scenarios were set: a Scenario in which the subjects rested at their desk for 15 minutes, and another one where subjects had to walk to a resting area provided with greenery and daylight.

Scenarios 1 and 2 did not have daylight, while Scenario 3 was used to experience the impact of technology developed by the Taisei Corporation, known as T-Light Cube.

As Figure 4a and 4b show, the fixed structure can capture direct sunlight from various altitudes throughout the year. Energy consumption for lighting is minimized by conveying outdoor light to the deeper interior and not just the area near the window.

Figure 4a. T-Light Cube. Source: Taisei Corporation, Japan.

Figure 4b. Photo of T-Light Cube. Mirrors system detail.

1.6. Environmental assessment.

Throughout the pilot experiment, in accordance with ASHRAE Standard 55 [3], the indoor and overall temperature, humidity, air velocity, CO₂ concentration, illumination and noise level were measured by four environmental measurements stations like the one shown in Figure 5. In accordance with the ASHRAE 55 Standard, the air renewal during the tests was 0.3 liter per second per square meter.

Figure 5. Environment measurement station used during the pilot experiment.

A continuous measurement of ambient temperature, relative humidity, overall temperature and wind speed was made at the height of 1.1 meters from floor level.

Likewise, the noise and CO₂ concentration were measured at 30-minute intervals, and the average value of illuminance on the work surface and vertical surface at the beginning of each work session. The average value of the CO₂ concentration was 886 (± 105) [ppm], and the noise was 49.9 (± 1.2) [dB].

The average value of the illuminance on the horizontal plane was 503.5 (± 15) [lx]. The conditions are different in group A and group B areas (Figure 4).

In the group A area, there is a direct contribution of natural light through the system described in Figure 5a and 5b, and the electric light is regulated in an automatic way guaranteeing a minimum of 500 lx at the daylight sensor. In group B area, there is no direct natural light contribution, but natural light is diffused, and the electric light is regulated automatically guaranteeing a minimum of 500 lx.

In accordance with the Hygienic Environment in Buildings regulations, the interior of the office was in standard conditions. Table IV shows the results obtained.

Table IV: Indoor Environment Measurement results during the pilot experiment ($\pm$ Standard Deviation).

Group	Morning		Afternoon	
	A	B	A	B
1.1m Temperature [°C]	24.4 $\pm$ 0.4	25.0 $\pm$ 0.4	24.6 $\pm$ 0.5	24.6 $\pm$ 0.4
Humidity [%]	38.1 $\pm$ 2.7	37.5 $\pm$ 3.0	40.0 $\pm$ 2.0	40.5 $\pm$ 2.3
Indoor Air Flow[m/s]	0.13 $\pm$ 0.08	0.15 $\pm$ 0.07	0.13 $\pm$ 0.08	0.14 $\pm$ 0.06
Overall Temperature [°C]	24.1 $\pm$ 0.4	24.9 $\pm$ 0.4	24.2 $\pm$ 0.4	24.4 $\pm$ 0.3
CO ₂ concentration[ppm]	832 $\pm$ 100	842 $\pm$ 105	939 $\pm$ 109	954 $\pm$ 127
Noise[dB]	50.1 $\pm$ 1.5	48.6 $\pm$ 0.9	49.7 $\pm$ 0.9	48.6 $\pm$ 1.2
Horizontal plane Illuminance [lx]	455 $\pm$ 22	1032 $\pm$ 303	425 $\pm$ 8	477 $\pm$ 57
Vertical plane Illuminance [lx]	232 $\pm$ 122	603 $\pm$ 117	211 $\pm$ 106	321 $\pm$ 39

1.6.1. Physiological assessment.

Physiological information, heart rate sympathetic activity value, salivary amylase activity value, blood pressure, tympanic membrane temperature, and the amount of activity were measured at the time intervals shown in Figure 6.

Figure 6. Physiological Measurement Schedule (Task Set 1, 2).

1.6.2. Psychological Assessment.

The analysis of psychological parameters was done through three questionnaires, which together provide a holistic view of the subjective perception of the subjects, from perception of space, the perception of subjective physical condition and perception of the subjective perception of workload.

Subsequently, the analysis of the correlation between physiological and psychological parameters allowed to objectify the latter.

QUESTIONNAIRE METHOD. SUBJECTIVE ASSESSMENT.

A Subjective Assessment of Workplace Performance – an SAP questionnaire survey was filled in by the subjects to analyze the environmental influence in the building, both comfort perception, and intellectual performance.

This survey had been studied at the Japan Sustainable Building Association, Japan Architectural Institute, Air Conditioning and Sanitation Engineering Society [78].

The degree satisfaction with the indoor environment was evaluated on a six-grade scale: thermal comfort, light, noise, air quality and space environment of both workplace and resting area. [136], [143], [148], [184].

QUESTIONNAIRE METHOD. JIKAKU-SHO SHIRABE QUESTIONNAIRE.

The Japan Occupational Health Committee proposed Jikaku-sho Shirabe questionnaire method in 2002 [154]. This questionnaire consists of 25 subjective fatigue symptom items. The physical condition, fatigue, drowsiness, subjective work efficiency before and after work, were also studied [78], [143], [148], [149], [154], [170], [184].

Therefore, subjective symptom research was also used for evaluating fatigue perception.

QUESTIONNAIRE METHOD. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION-TASK LOAD INDEX (NASA-TLX).

Although workload assessment techniques abound, subjective ratings are the most commonly used method and are the criteria against which other measures are compared. In most operational environments, one of the problems encountered with the use of subjective rating scales has been the large degree of variability [60], [61], [108].

NASA TLX is a rating technique by which variability is reduced. NASA TLX, which is multidimensional, provides a method through which specific sources of workload relevant to a given task can be identified and considered in computing an overall workload rating.

It combines information about these factors, thereby reducing some sources of between-subject variability that are experimentally irrelevant in the pilot, and emphasizing the contributions of other sources of variability that are experimentally relevant in the pilot [60], [61], [108].

1.6.3. Statistical methods.

The correlation between variables was measured by a statistic called the **correlation coefficient** or **Pearson's correlation coefficient**, which represents the strength of the putative linear association between the variables in question. It is a dimensionless quantity that takes a value within the range -1 to +1.

A correlation coefficient of zero indicates that no linear relationship exists between two continuous variables and a correlation coefficient of -1 or +1 indicates a perfect linear relationship. The strength of the relationship can be anywhere between -1 and +1.

The stronger the correlation, the closer the correlation coefficient comes to ± 1 . If the coefficient is a positive number, the variables are directly related.

On the other hand, if a coefficient is a negative number, the variables are inversely related [100].

1.6.4. Simulated work content.

Using the typing software "C-Type," the subjects type a US English text, for measuring the efficiency of simple work. When the input of one of the text file is complete, the typing speed, batting number, and batting average are measured automatically.

In Mind Map Task, the words are associated with one word, as Figure 88 shows. We need as many answers as possible within the time, to evaluate the knowledge creation. This task is performed on a paper.

1.7. Results.

A representative sample of the measurements made in this Case Study can be consulted in Annex I of this Thesis document.

CORRELATION BETWEEN BIOPHILIC DESIGN VARIABLES AND PSYCHOLOGICAL QUANTITY.

For the unification of conditions, in the morning questionnaire, we exclude those who were not in the best physical condition, those who drank alcohol the night before, and those who did not have breakfast.

A positive correlation is found in physical health, drinking alcohol, and breakfast with the results of the tasks. Also, since the influences of hunger and fatigue in the morning and afternoon are different, we analyze each result separately.

Table V shows the most significant factors correlated with the presence of greenery in the workplace.

Table V: Correlation analysis result of satisfaction about greenery degree and psychological quantity.

"Was thermal sensation appropriate?"	0.560**
"Do you feel awake?"	0.490**

** $p < 0.01$ (bilateral). N= 27

Table VI shows the most significant factors correlated with the presence of daylight in the workplace. There is a correlation between daylight satisfaction and the capacity for concentration, fatigue, work efficiency, and motivation.

Table VI: Correlation analysis result of the presence of daylight and psychological quantity

Capacity for concentration (1: not possible ~ 6: very easy)	0.693**
Feeling of Exhaustion (1: very tired ~ 9: not at all tired)	0.562**
Subjective work efficiency (%)	0.662**
Motivation (%)	0.692**

** $p < 0.01$ (bilateral). N= 27

SATISFACTION WITH THE GREENERY.

Before the pilot experiment, during the recruitment period, students are asked about possible allergies to plants, selecting only those people who do not present any pathology.

During the five days in which the pilot experiment is carried out, the groups of people who occupy the workspace with greenery are asked about their satisfaction with it. Figure 7 shows that 73% of the people say they are satisfied or very satisfied with the greenery, highlighting on day 2, where 100% stated that they are satisfied or very satisfied.

Figure 7. Satisfaction rate about greenery, among people exposed to the presence of greenery every day.

INFLUENCE OF THE USE OF BIOPHILIC DESIGN ON STRESS CONDITION.

The results of the concentration of saliva amylase after working in a space with greenery, and in space without greenery, are shown in Figure 8.

By measuring the concentration of saliva amylase, it is possible to understand the state of stress at that time. There is a significant difference of 12.17 points between Scenario 1 and Scenario 3 in the morning.

Figure 8. The concentration of saliva amylase in each scenario (Scenario 1, blue: no daylight, no greenery; Scenario 2, green: no daylight, greenery; Scenario 3, orange: Daylight and greenery).

The relationship between the sympathetic activity LF / HF while working in the presence or absence of daylight in the workspace is analyzed. The difference from the resting value of each day for each subject is calculated and taken as a relative value to eliminate individual differences between days.

Moreover, we exclude the samples in which the sympathetic state at rest is outside of the normal distribution. It is thought that it is desirable that sympathetic nerves be active and in a state of alertness while working.

As Figure 9 shows, sympathetic activity is 0.25 points higher ($p < 0.10$) in the morning and 0.26 points higher ($p < 0.05$) in the afternoon ($p < 0.05$) in the Scenario with daylight, compared to the Scenario without daylight.

Figure 9. Sympathetic activity while working LF/HF. Scenario 2, blue, $n = 72$.

Scenario 3, green, $n = 72$

RELATIONSHIP BETWEEN BIOPHILIC DESIGN AND THERMAL SATISFACTION.

As seen in Table V, the thermal sensation is strongly correlated with the presence or not of greenery in the workplace. According to the answers obtained in the questionnaire,

Figure 10 shows that there is no significant difference in the satisfaction with the thermal sensation between scenarios 1 and 2. However, a notable difference occurs when scenario 1 (without natural light and without greenery) and scenario 3 (with natural light and greenery) are compared. 7,68% more of the people stated that thermal sensation is adequate or very adequate.

Figure 10. Answer percentages to the question: " Did you feel that the thermal sensation was adequate?" Scenario 1= scenario 1, Scenario 2= scenario 2, Scenario 3= scenario 3

RELATIONSHIP BETWEEN BIOPHILIC DESIGN AND DROWSINESS.

There is a significant correlation between the presence of greenery and daylight and the subjective feeling drowsiness as stated in the Jikaku-sho Shirabe questionnaire.

Figure 11 shows that the percentage of people who feel "sleepy" or "very sleepy" descends by 6.2% between Scenario 1 and Scenario 2 on the morning and 9.4% between scenario 1 and scenarios 2 and 3 in the afternoon.

Figure 11. Drowsiness reporting ratio. Scenario 1= scenario 1, Scenario 2= scenario 2, Scenario 3= scenario 3

INFLUENCE OF BIOPHILIC DESIGN ON THE SUBJECTIVE WORKLOAD.

Previous results of the tasks are analyzed. It is noted that none of the eight subjects showed abnormal performance results.

The results of the NASA TLX test are shown in Figure 12. The workload sensation is significantly lower in scenario 3, with the combined presence of daylight and greenery, compared with scenarios 1 and 2.

In the morning session, the difference obtained between scenario 1 and scenario 3 is 10.8 points ($p < 0.1$) and 9.8 points ($p < 0.1$) between scenario 2 and scenario 3. In the afternoon session, the difference obtained between scenario 1 and scenario 3 is 13.8 points ($p < 0.05$) and 13.7 points ($p < 0.05$) between scenario 2 and scenario 3.

Figure 12. Workload ratio. Scenario 1= scenario 1, Scenario 2= scenario 2, Scenario 3= scenario 3

RELATIONSHIP BETWEEN BIOPHILIA AND INTELLECTUAL PERFORMANCE.

The results of tasks are analyzed. It is established that none of the eight subjects showed abnormal performance results.

To eliminate individual capacity differences, the typing and mind map results are normalized and analyzed. Additionally, the results from the first day are excluded, taking into consideration the effects of inexperienced work. [119].

Figure 13 shows that number of effective batting in the typing task, which is not a creative task, is 4.93 points higher ($p < 0.05$) between scenario 1 and scenario 3 in the morning and 3 points higher between scenario 1 and scenario 3 in the afternoon.

Figure 14 shows that the number of effective responses to the mind map, which is a creative task, is 5.4 points higher ($p < 0.05$) between scenario 2 and scenario 3 in the morning and 1.6 points higher between scenario 1 and scenario 3 in the afternoon ($p < 0.15$).

Figure 13. Results of the typing task in each scenario. Scenario 1= scenario 1, Scenario 2= scenario 2, Scenario 3= scenario 3

Figure 14. Results of the mind map task in each scenario. Scenario 1= scenario 1, Scenario 2= scenario 2, Scenario 3= scenario 3

1.8. Discussion.

In this research, the pilot experiment is conducted with the aim of testing the tool developed to quantify the greenery and daylight impact on the workplace and intellectual performance, through a correlation of results, physiological tests, psychological tests, and simulated work tasks.

It is necessary to bear in mind that daylighting results are highly dependent on the time of year since the ratio of daylight to electric lighting could be different at any other point in the year or in a different climate.

There is a positive correlation between the presence of greenery and satisfaction with the thermal environment, and there is a negative correlation between greenery and daylight satisfaction and the subjective perception of fatigue.

There is no significant difference in satisfaction with the thermal sensation between scenarios 1 and 2. However, a notable difference occurs when scenario 1 (without daylight or greenery) and scenario 3 (the opposite of Scenario 1: with daylight and greenery) are compared.

In the latter Scenario, 7,68% more of the subjects stated that the thermal sensation is adequate or very adequate.

It is important to highlight that the three groups are under the same ambient temperature conditions, which demonstrates that the biophilic design positively affects the subjective perception of thermal comfort.

The use of daylight in the workplace showed the possibility of reducing the feeling of fatigue. By using daylight in the workplace, the subjective workload evaluation score using NASA-TLX is 0.99 points lower in the morning and 0.2 points lower in the afternoon. From this, it is shown that use of daylight in the workplace could contribute to a perceived reduction in workload among the workforce.

Workload sensation is significantly lower in scenario 3, compared with scenarios 1 and 2. The most notable result is obtained when we compare the results in the afternoon session, with a difference of 13.80 points, suggesting that a greater psychological decrease in the workload is achieved when we combine the variables of daylight and greenery.

In the presence of greenery, the percentage of subjective drowsiness perception descends 6.2% in the morning and 9.4% in the afternoon. It is interesting to note that although the presence of greenery has an impact on the subjective perception of drowsiness, physiological tests indicate that the presence of daylight has an objective impact on the reduction in drowsiness.

By using daylight in the workplace, the activation of sympathetic nerves while working is confirmed, with an increase of 25 points in the presence of daylight and greenery concerning the presence of greenery during the morning session. There is an increase of 26 points in the presence of daylight and greenery concerning the presence of just greenery during the afternoon session, indicating an increase in wakefulness.

About other physiological indicators, the results conclude that there is a decrease in the concentration of saliva amylase of up to 10.1 points, which means a decrease in the stress levels with the presence of greenery.

In relation to objective intellectual performance according to the results in the tasks of simulated work, there is no significant difference in the number of typing mistakes in daylight.

The effective number of answers about the mind map is 5.4 points higher in the morning and 1.6 points higher in the afternoon, comparing the Scenario with daylight with the Scenario without daylight.

From this, it is shown that the use of daylight in the office space does not contribute to an improvement in the work efficiency of simple work but may contribute to the performance of creative work. From the above, it is shown that the use of daylight in the office workspace could contribute an improvement in creative work performance through activation of the sympathetic nerve, a reduction in the feeling of fatigue, and a reduction in the workload.

The task results are not significantly different between Scenarios in the morning or the afternoon. Although the presence of greenery in the workplace does not contribute to the enhancement of work efficiency, it is necessary to point out that other factors could affect the result, such as the lack of illumination.

A reduction in self-reported symptoms and an improvement in environmental perceptions as subjective indicators support previous research in biophilic spaces. [Human Spaces, 2015], [Human Spaces, 2011].

It is important to mention that the objective of this Case Study is to demonstrate the potential of the tool, comparing different scenarios.

However, it is not possible to indicate the necessary amount of lighting or greenery to achieve a universal optimal result, since there are no universal recipes, but the design will be tailored to each environment, including issues such as the characterization of the building and the culture of the company.

1.9. Conclusions.

The tool tested with this Case Study allows the influence of some variables in well-being and workplace performance to be quantified, and it will lead to greater knowledge in productivity and creativity in the workplace, and how it could be improved.

The findings with this pilot experiment, point to additional benefits to performance, creativity, user well-being and health in biophilic designed workplaces, by combining greenery and daylight.

In a five-day pilot experiment, participants in biophilic space have 4.92 points more in creative task scores, better environmental perceptions, and fewer symptoms than those in the control space.

Findings suggest that the quantifiable benefits of the biophilic workplace go beyond measurable physiological indicators. Greenery and daylight may play a major role in the occupants' health and cognitive function, and both could be assessed through the measurement of subjective and objective parameters.

2. CASE STUDY 2

2.1. Abstract.

With intellectual performance as economic and social factor key, the purpose of this pilot experiment was to quantify variables and to assess how much greenery and interior wood influence users' perceptions, and its effect on performance, creativity, well-being, and health.

Using two offices in the same building, one with interior wood and one as a control office, users' perceptions were examined using a holistic tool, administered to a pilot experimental group and a control group before and after the installation of greenery. The results were analyzed to determine any statistically significant differences between the groups.

The hypothesis was that the combination of greenery and interior wood might provide an effective method of regulating the indoor conditions within buildings. This can potentially lead to performance gains for companies and increasing well-being, creativity and performance among the workforce.

The findings with this pilot experiment, point to additional benefits to performance, creativity, user well-being and health in biophilic designed workplaces, by combining greenery and interior wood. In a six-day pilot experiment, participants in biophilic space have 7,14 points more in creative task scores, better perceptions, and fewer symptoms than those in the control space.

2.2. Introduction.

A tool has been designed to quantify the influence of the use of biophilic design on intellectual performance, creativity, and well-being. The tool has been verified by a pilot experiment carried out through physiological tests, psychological tests, and simulated work tasks.

Although previous studies have shown associations between indoor stressors and comfort, health and productivity in an office environment, relevant relations between greenery and interior wood combination as biophilic design and effects have been difficult to establish.

2.3. Objectives.

The purpose of this pilot experiment was to quantify variables and to assess how much greenery and interior wood influence users' perceptions, and its effect on performance, creativity, well-being, and health.

2.4. The Tool.

A pilot experiment was scheduled with both subjective and objective evaluation, to quantify subjects' performance. Users' perceptions were examined using a questionnaire. For objective assessment, physical and physiological parameters were measured. Furthermore, daily tests were carried out for temperature, relative humidity, CO₂, and light. Table I summarizes all the items measured.

Table I: Pilot experiment measurement items.

	Item	Method	Time
Physiological measurements	Autonomic nerves	Heart rate	Continuous
	Activity level	Activity meter	
	Sleeping latency and efficiency	Sleep gauge	At home
	Saliva amylase concentration	Saliva amylase activity monitor	
Psychological measurements	Fatigue	-	Before and after work
	drowsiness		
	Indoor environmental satisfaction	Questionnaires	
	Subjective working efficiency		During work
	Objective work efficiency: typing (information processing work), mind map (knowledge creation work)	Tasks	
Environmental measurements	Light (lx)		1-minute interval
	Temperature (°C)		
	HR (%)		
	Radiation temperature (°C)	Environmental measurement station	
	Wind speed (m/s)		30-minute interval
	CO ₂ concentration (ppm)		
	Noise (dB)		

The pilot experiment with subjects was carried out in a laboratory environment of Nice Company for a total of 6 days.

The study group was characterized as follows: subjects were four male and four females, college students, with a standard body type ($18.5 < \text{Body Mass Index (kg/m}^2) < 25.0$) and non-smokers.

In this Case Study, they performed a series of tasks simulating office work, with three tasks set in the morning, and three in the afternoon (Fig. 1).

The daily pilot experimental schedule was shown in Figure 1. The subjects were placed in the simulated environment at 12:00 a.m. Firstly, they answered a questionnaire about the activities of their previous day. After that, a 120-minute session started, with a physiological measurement, questionnaire and simulated work with two different tasks. Before and after the pilot experiment, the subjects had some free time.

However, strenuous exercise or drinking alcohol were forbidden. Table II shows the pilot experiment setup combining the three Scenarios. Each Scenario combines greenery and interior wood as variables.

It has been demonstrated that performance decreases when the end time is close. Task Set three was added with the aim of not compromising the results of Task Set one and two, and results of Task Set three were not considered, eliminating the "end time effect" [35].

Figure 1. Pilot experiment schedule.

Table II shows the pilot experimental design in the total of the four Scenarios:

- Scenario 1: no wood, no greenery
- Scenario 2: wood, no greenery
- Scenario 3: wood, greenery
- Scenario 4: no wood, greenery

Table II. Pilot experimental schedule and Scenarios.

		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6
GROUP A	Subject 1	Scenario 1	Scenario 1	Scenario 1	Scenario 4	Scenario 4	Scenario 4
	Subject 2	Scenario 1	Scenario 1	Scenario 1	Scenario 4	Scenario 4	Scenario 4
	Subject 3	Scenario 1	Scenario 1	Scenario 1	Scenario 4	Scenario 4	Scenario 4
	Subject 4	Scenario 1	Scenario 1	Scenario 1	Scenario 4	Scenario 4	Scenario 4
	Subject 5	Scenario 2	Scenario 2	Scenario 2	Scenario 3	Scenario 3	Scenario 3
	Subject 6	Scenario 2	Scenario 2	Scenario 2	Scenario 3	Scenario 3	Scenario 3
	Subject 7	Scenario 2	Scenario 2	Scenario 2	Scenario 3	Scenario 3	Scenario 3
	Subject 8	Scenario 2	Scenario 2	Scenario 2	Scenario 3	Scenario 3	Scenario 3

Scenario 1 corresponds to the control group. In Scenario 3 and Scenario 4, one unit of Bamboo plant, one unit of Snake plant, one unit of Areca palm, one unit of Chrysanthemum, one unit of Spider Plant and one unit of Golden Pothos were placed in the workplace. The plants were selected according to the classification made by the NASA study of plants [53], [179].

Table III summarizes the main characteristics of the selected plants and Figure 2 shows the pilot experiment layout with the position of the greenery. Table IV shows the two different rooms with and without interior wood.

Table III: Selected greenery.

Name	Bamboo Palm	Sansevieria Trifasciata	Areca Palm
Size	Large	Large	Large
Picture			
Name	Chrysanthemum	Spider Plant	Golden Pothos
Size	Medium	Medium	Small
Picture			

Figure 2: Pilot experiment place layout.

Table IV. Two different rooms.

Rate	0% wood	45% wood
Picture		
Ceiling	Vinyl cloth	Natural wood (cypress), light color, unpainted, solid panels
Wall	Vinyl cloth	Vinyl cloth
Floor	Composite flooring	Natural wood (cypress), light color, unpainted, solid panels

2.4.1. Environmental assessment.

Throughout the pilot experiment, in accordance with ASHRAE Standard 55 [3], in each Case Study the following parameters were measured:

- Ambient lighting: (1) surface level lighting desk, (2) vertical illuminance, color temperature (3), (4) brightness distribution.
- Ambient temperature: (5) air temperature, relative humidity (6), (7) radiation temperature, indoor air flow (8), (9) thermography.
- Indoor Air Quality: CO₂ concentration (10).
- Noise: (11) level of background noise.
- External environment: (12) outdoor temperature and humidity, wind speed, and direction, (13) level of illumination of the sky.
- Situation observed: (14) percentage of holes in the facade, number of people, swaddling level, lighting work areas.

Equipment mentioned and measurement method was shown in Table V.

Table V. Environmental equipment and measurement method.

Measuring element	Measurement equipment	Measurement method
(1) Desk illuminance [lx]	Luminometer	Continuous measurement every 5 minutes.
(2) Vertical illuminance [lx]	Color temperature meter	
(3) Color temperature [K]		
(4) Brightness distribution [cd / m ²]	Brightness distribution measurement instrument.	Continuous measurement every 60 minutes.
(5) Air temperature [°C]	Automatic measurement of temperature and humidity.	Continuous measurement every 5 minutes.
(6) HR [%]		
(7) Radiant temperature [°C]	Globe	Continuous measurement every 5 minutes.
(8) Indoor air flow [m / s]	Anemometer	Continuous measurement every 5 minutes.
(9) Termography	Infrared camera.	Measurement every 60 minutes.
(10) CO ₂ concentration [ppm]	Air indoor quality system.	Measurement every 60 minutes.
(11) Noise [dB]	Noise meter	Measurement every 60 minutes.
(12) Exterior temperature, humidity, wind.	BEMS.	Continuous measurement every 60 minutes. (Also in combination with data from the Meteorological Agency).
(13) Level of illumination of the sky.	Luminometer	Continuous measurement every 5 minutes.
(14) Voids, number of people, swaddling, illumination of the work area.	Visually.	Fixed observation point every 60 minutes.

In the space with 0% of wood, the average value of the CO₂ concentration was 1310,09 (± 105) [ppm], the temperature was 26,27 °C ($\pm 0,4$), the relative humidity was 70,6 ($\pm 2,7$), the noise was 49.9 (± 1.2) [dB], the horizontal illuminance at the working plane was 503.5 (± 15) [lx].

In the space with 45% of wood, the average value of the CO₂ concentration was 1258,8 (± 127) [ppm], the temperature was 26,31 °C ($\pm 0,4$), the relative humidity was 69,21 ($\pm 2,5$), the noise was 49.7 (± 1.2) [dB], the horizontal illuminance at the working plane was 500.5 (± 15) [lx].

According to Hygienic Environment in Buildings regulations, the interior of the office was in standard conditions. Table VI summarizes the results of environment measurement. The high levels of CO₂ concentration are due to the opening of windows during breaks and the time when the experiment was not carried out.

Table VI. Environmental results.

	0% wood	45% wood
CO ₂ concentration (ppm)	1310,09 (± 105)	1258,8 (± 127)
Temperature (°C)	26,27 ($\pm 0,4$)	26,31 ($\pm 0,4$)
Relative Humidity (%)	70,6 ($\pm 2,7$)	69,21 ($\pm 2,5$)
Noise (dB)	49.9 (± 1.2)	49.7 (± 1.2)
Horizontal illuminance (lx)	503.5 (± 15)	500.5 (± 15)

2.4.2. Physiological assessment.

Physiological information, heart rate, salivary amylase activity value, blood pressure, tympanic membrane temperature, and the amount of activity were measured according to time intervals shown in Figure 3.

Figure 3. Physiological Measurement Schedule (Task Set 1, 2).

As physiological information, heart rate, brain waves, salivary amylase activity value, blood pressure, tympanic membrane temperature, the amount of activity were measured.

In the chronological analysis of the changes in the autonomic nervous system at the time of the pilot experiment, the measurement of the heart rate was continuous.

Also, to understand subject's activity in the morning, the measurement of the amount of activity was also continuous. The amount of activity was measured in free time and in pilot experiment time.

To discard abnormal states of stress state of the subjects, blood pressure was measured before, during and after the work.

Blood pressure performed two measurements at each time. To understand the subject's brain state in a relaxed state and working state, brain waves were measured before and after work with a simple electroencephalograph.

The salivary amylase activity value was obtained between tasks, to analyze the stress level of the subject. Furthermore, to understand the physical condition of the subject, eardrum temperature was measured before and after work. It should be noted that, in order to understand the impact of the menstrual cycle only in female subjects, saliva estrogen was measured once.

Because sleep habits also affect the sleep state during the pilot experiment period, a sleep meter was installed at the home of each subject for one week and the pilot experimental period previous to the pilot experiment, to measure the previous sleep state.

In addition, the thermal environment of the bedroom affects the sleep efficiency, so temperature and humidity meter were installed in the bedroom.

Further, the female subject's sublingual temperature was measured before the pilot experiment, during the pilot experiment and for one week after the pilot experiment week because of the effect of the menstrual cycle.

Table VI. Physiological equipment and measurement method.

Item measured	Measuring instrument		Measurement time	Measurement method
Heartbeat	multi-function monitor	wireless Holter (CarPod).	During the pilot experiment time.	electrodes (transmitter) attached to the two positions, to a portable receiver.
Salivary amylase activity value	salivary monitor.	amylase	Before, during and after work.	the leading edge of the sheet of salivary amylase test was placed under the tongue, and after it was inserted into the monitor.
Blood pressure	sphygmomanometer (OMRON HEM-7080IT)		Before, during and after work	winding the cuff on the arm, to measure the blood pressure.
Brainwaves	Simple electroencephalograph (NeuroSky Inc. MindWave Mobile)		Before and after work.	attached to the forehead, carry out the measurement.

Eardrum temperature	ear thermometer (OMRON MC-510)	Before and after work.	the measurement part was inserted into the ear, to measure the eardrum temperature.
Activity Amount	Activity meter (Active style Pro HJA-350IT)	The duration of the pilot experiment (including the free time)	attached to the waist with a clip, to measure the number of steps and activities strength and the like by the three-axis acceleration sensor.

Saliva estrogen (female subjects only)	saliva instrument (SCA) and a dedicated tube.	sampling Once each pouring to collect saliva by salivation to the SCA using a special tube.

Sleep meter HSL-102M)	sleep meter (OMRON HSL-102M)	during sleep time at home	the sleep meter aside of the futon, to measure the sleep state by sensing the motion in the weak radio waves.

Sublingual temperature (female subjects only)	Women (MC-642L).	thermometer one before pilot experiment and one week after the pilot experiment.	week the make a measurement putting under the tongue the sublingual temperature gauge.

2.4.3. Psychological Assessment.

The analysis of psychological parameters was done through three questionnaires, which together provide a holistic view of the subjective perception of the subjects, from the perception of space, the perception of subjective physical condition and perception of the subjective perception of workload.

Subsequently, the analysis of the correlation between physiological and psychological parameters allowed to objectify the latter.

QUESTIONNAIRE METHOD. SUBJECTIVE ASSESSMENT.

A Subjective Assessment of Workplace Performance questionnaire survey was conducted among the subjects to analyze the environment influence in this building both, on comfort perception and intellectual performance. This survey had been studied at the Japan Sustainable Building Association, Japan Architectural Institute, Air Conditioning and Sanitation Engineering Society [78].

Indoor environment satisfaction degree was evaluated in six-grade scale: thermal comfort, light, noise, air quality and space environment of both workplace and resting area [136], [143], [148], [184].

QUESTIONNAIRE METHOD. JIKAKU-SHO SHIRABE QUESTIONNAIRE.

The Industrial Fatigue Research Committee of the Japan Occupational Health proposed Jikaku-sho Shirabe in 2002 [154]. This questionnaire consists of 25 subjective fatigue symptom items.

Physical condition, fatigue, drowsiness, subjective work efficiency before and after work, were also studied [78], [143], [148], [150], [154], [170], [184]. Therefore, subjective symptom investigation was also used for evaluating fatigue perception.

QUESTIONNAIRE METHOD. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION-TASK LOAD INDEX (NASA-TLX).

Notwithstanding disagreement about its nature and definition, workload remains an critical, practically relevant and measurable entity. Although workload assessment techniques abound, subjective ratings are the most commonly used method and are the criteria against which other measures are compared. In most operational environments, one of the problems encountered with the use of subjective rating scales has been high variability [60], [61], [108].

NASA TLX is a rating technique by which variability is reduced. NASA TLX, which is multidimensional, provides a method by which specific sources of workload relevant to a given task can be identified and considered in computing a global workload rating.

It combines information about these factors, thereby reducing some sources of between-subject variability that are pilot experimentally irrelevant, and emphasizing the contributions of other sources of variability that are pilot experimentally relevant [60], [61], [108].

2.4.4. Statistical methods.

The correlation between variables was measured by a statistic called the **correlation coefficient or Pearson's correlation coefficient**, which represents the strength of the putative linear association between the variables in question [100].

Pearson's correlation coefficient is denoted by "r" in Formula 1.

2.4.5. Simulated work content.

By using the typing software "C-Type," the subjects type a US English text, for measuring the efficiency of simple work. When the input of one of the text file was complete, the typing speed, batting number, and batting average were measured automatically.

In Mind Map Task, the words were associated with one word. We need as many answers as possible within the time, to evaluate the knowledge creation. This task was performed on a paper.

In Addition Task, three two-digit numbers were displayed by a time on a PC. Within the time limit, the subject must answer the total result on a paper, to evaluate the work performance based on the number of correct answers.

Sudoku task consists into the 9×9 square on paper, fitting a number from 1 to 9. The rules were as follows: do not use the same number in the same column, do not use the same number in the same line, do not use the same number in each block (3×3 square).

2.5. Results.

A representative sample of the measurements made in this Case Study can be consulted in Annex II of this Thesis document. The formats of the questionnaires used can also be consulted in Annex III.

CORRELATION BETWEEN BIOPHILIC DESIGN VARIABLES AND PSYCHOLOGICAL QUANTITY.

For the unification of conditions, in the morning questionnaire, we exclude those who were not in the best physical condition, those who drank alcohol the night before, and those who did not have breakfast.

A positive correlation was found in physical health, drinking alcohol, and breakfast with the results of the tasks. Also, since the influences of hunger and fatigue in the morning and afternoon were different, we analyze each result separately.

No correlation was found between Scenarios 2 or 4 and the results obtained, so Table VII shows the most significant factors correlated with the presence of greenery and interior wood (Scenario 3) in the workplace.

There was a positive correlation between the combination of greenery and interior wood and sleep efficiency, and there was a negative correlation between the combination of greenery and interior wood and saliva amylase concentration, a number of awaked times during the night, headache after work, no concentration in creative tasks before work and sympathetic nerves activity.

Table VII: Correlation analysis result of success rate in tasks and physiological and psychological quantity in Scenario 3

Saliva amylase concentration	-0,537* (n=15)
Sleep efficiency	0,760** (n= 15)
Number of awaked times during the night	-0,773** (n= 15)
Headache after work	-0,639** (n= 32)
No concentration in creative tasks before work	-0,568** (n= 31)
Sympathetic nerves activity	-0,533** (n= 32)

** $p < 0.01$ (bilateral)

* $p < 0.05$ (bilateral)

INFLUENCE OF UTILIZATION OF BIOPHILIC DESIGN ON STRESS CONDITION.

The results of the concentration of saliva amylase after working in Scenario 1 and Scenario 3, were shown in Figure 4.

By measuring the concentration of saliva amylase, it was possible to understand the state of stress at that time. There was a significant difference of 12,30 KIU/L between Scenario 1 and Scenario 3.

Figure 4. The concentration of saliva amylase in each Scenario (Case 1=Scenario 1: no greenery, no wood; Case 3= Scenario 3: greenery and wood).

Figure 5 shows that the percentage of a headache after work decreased 11,25% ($p < 0.01$), between Scenario 1 and Scenario 3.

Figure 5. Results of a headache after work reported in Scenario 1 (blue) and Scenario 3 (green)

The relationship between the sympathetic activity LF / HF while working in the presence or absence of greenery and interior wood in the workspace was analyzed.

The difference from the resting value of each day for each subject was calculated and taken as a relative value to eliminate individual differences between days. Moreover, the samples in which the sympathetic state at rest was outside of the normal distribution were excluded.

It was thought that it was desirable that sympathetic nerves be active and in a state of alertness while working. As Figure 6 shows, sympathetic activity was 0.0137 points higher ($p < 0.10$) in the morning in the Scenario of greenery and interior wood, compared to the Scenario without them.

Figure 6. Sympathetic activity while working in the morning LF/HF reported in Scenario 1 (blue) and Scenario 3 (green)

THE RELATIONSHIP BETWEEN BIOPHILIC DESIGN AND SLEEP QUALITY.

There was a significant correlation between the presence of greenery and wood and the sleep efficiency and the number of times awakened through the night. Figure 7 shows that the percentage of sleep efficiency increased by 1,37% between Scenario 1 and Scenario 3. The number of times awakened decreased 0,26 times, as Figure 8 shows.

Figure 7. Sleep Efficiency (Case 1=Scenario 1: no greenery, no wood; Case 3= Scenario 3: greenery and wood).

Figure 8. Number of times awakened (Case 1=Scenario 1: no greenery, no wood; Case 3= Scenario 3: greenery and wood).

THE RELATIONSHIP BETWEEN BIOPHILIA AND INTELLECTUAL PERFORMANCE.

The results of the tasks were analyzed. It was established that none of the eight subjects showed abnormal performance results.

To eliminate individual capacity differences, the tasks results were normalized and analyzed [63]. Additionally, the results from the first day were excluded, taking into consideration the effects of unskilled work [119].

Figure 9 shows that the number of effective batting in the typing task, which was not a creative task, decreased 5,60 points ($p < 0.05$), between Scenario 1 and Scenario 3.

The number of the effective rate addition task and sudoku task, which were not a creative task, were equal between Scenario 1 and Scenario 3. The number of the effective rate in mind map task, which was a creative task, increased 7,14 points ($p < 0.05$), between Scenario 1 and Scenario 3.

Figure 9. Results of tasks in each Scenario 1 and Scenario 3 (Case 1=Scenario 1: no greenery, no wood; Case 3= Scenario 3: greenery and wood).

Figure 10 shows that the percentage of concentration in the creative task before work increased 1,12% ($p < 0.05$), between Scenario 1 and Scenario 3.

Figure 10. Results of concentration in creative tasks before work reported in each Scenario 1 (blue) and Scenario 3 (green)

2.6. Discussion.

In this research, the pilot experiment was conducted with the aim of testing the tool developed to quantify the greenery and wood-interior impact on the workplace and intellectual performance, through a correlation of results, physiological tests, psychological tests, and simulated work tasks.

There was no correlation between the isolated presence of greenery (Scenario 4) and the isolated presence of wood (Scenario 2), while there was a correlation between the combined presence of both variables (Scenario 3).

Analyzing the data, we found that in the environment perception questionnaire, participants consider that a natural environment was not perceived when only one of the variables was present.

However, when both variables were combined, the participants perceived their environment as highly natural. From the above, it was suggested that the psychological perception of the environment was an essential factor in the results.

There was a positive correlation between the presence of greenery and wood and sleep efficiency, and there was a negative correlation between greenery and wood and saliva amylase concentration, number of awakened times during the night, headache after work, lack of concentration in creative tasks and activation of the sympathetic nervous system.

In the presence of greenery and wood, the percentage of sleep efficiency increased by 1,37% and the number of times awakened decreased 0,26 times between Scenario 1 and Scenario 3.

By using greenery and wood in the workplace, the activation of sympathetic nerves while working was confirmed, with an increase of 0.0137 points ($p < 0.10$) in the morning, indicating an increase in wakefulness.

About other physiological indicators, the results conclude that there was a decrease in the concentration of saliva amylase of up to 12,30 KIU/L, which means a decrease in the stress levels with the presence of greenery and wood.

There was no significant difference in performance in addition task and sudoku task with the thermal sensation between Scenarios 1 and 3. However, a notable difference occurs when typing task (no-creative task) and mind map task (creative task) were compared.

In the first Scenario, the performance decreased 5,60 points ($p < 0.05$), between Scenario 1 and Scenario 3. In the latter Scenario, increased 7,14 points ($p < 0.05$), between Scenario 1 and Scenario 3.

Furthermore, the subjects reported 1,12% ($p < 0.05$) more concentration in creative tasks before work between Scenario 1 and Scenario 3.

From this, it was shown that the use of greenery and wood in the office space did not contribute to an improvement in the work efficiency of simple work but may contribute to the performance of creative work.

From the above, it was shown that the use of greenery and wood in the office workspace could contribute an improvement in creative work performance through activation of the sympathetic nerve, a reduction in a headache after work, and an improvement concentration in creative tasks.

The task results were not significantly different between Scenarios in the morning or the afternoon. However, previous research has established that some variables of the biophilic design, such as daylight, do impact differently between Scenarios in the morning and the afternoon [8], [9].

Analyzing the results obtained in the present study and the previous ones, it was suggested that greenery and wood were not variables that affect differently in the morning and the afternoon.

It was important to mention that the objective of this study was to demonstrate the potential of the tool presented in this research, comparing different scenarios.

However, it was not possible to indicate the necessary amount of greenery and wood to achieve a universal optimal result, since there were no universal recipes, but the design will be tailored to each environment, including issues such as the characterization of the building and the culture of the company.

2.7. Conclusions.

The tool tested with this pilot experiment allows the influence of some variables in well-being and workplace performance to be quantified, and it will lead to greater knowledge in productivity, creativity, and well-being in the workplace, and how it could be improved.

The findings with this pilot experiment, point to additional benefits to performance, creativity, user well-being and health in biophilic designed workplaces, by combining greenery and interior wood.

In a six-day pilot experiment, participants in biophilic space have 7,14 points more in creative task scores, better perceptions, and fewer symptoms than those in the control space.

Findings suggest that the quantifiable benefits of the biophilic workplace go beyond measurable physiological indicators.

Greenery and interior wood may play a significant role in the occupants' health and cognitive function, and both could be assessed through the measurement of subjective and objective parameters.

3. CASE STUDY 3

3.1. Introduction.

According to the report "Fast Forward 2030: The Future of Work and the Workplace" [20] published by CBRE in October 2014, in the year 2030, the world of work will revolve around social and creative intelligence instead of repetitive tasks, and High-Performance Workplace will be an essential tool to boost the competitive advantage of organizations.

To quantify the influence of workplace in the increase of productivity, creativity and well-being, a tool has been developed with psychological, physiological and simulated work tasks.

The results highlight an increase of 63.34% in productivity and 137.50% in creativity when we combine a biophilic designed workplace, physical activity and meditation and adequate training in the use of the space.

The tool developed and tested opens a way to improve productivity in the workplace in a much larger proportion now known.

3.2. Objectives.

With well-being and productivity in work environments as a critical economic and social factor, since the loss of productivity for companies means a cost of up to 550,000 million per year [145], the objective of this scientific study is to test a Tool that quantifies the perceptions of people and the effect on their productivity, and well-being in relation to the design and culture of environments focused on the experience of people.

3.3. The Tool.

An experiment was proposed to quantify the increase in well-being and productivity, according to the proposed tool.

The experiment was designed combining objective and subjective evaluation. The psychological perception of the subjects was examined using the Perceived Stress Scale questionnaire [25], Subjective Assessment of Workplace Performance questionnaire [78], [136], [143], [148], [184], Sleep Habits questionnaire [3], Short International Physical Activity questionnaire [32] and the Scale for Mood Assessment questionnaire [134].

For the objective evaluation, physiological parameters were measured for the three experimental groups and the control group, before and after the implementation of the proposed activities and the different workplaces.

The results were analyzed to determine any statistically significant difference between the groups.

In addition, a daily monitoring of temperature, relative humidity, CO₂, lighting and noise was carried out. Table I summarizes all the measured parameters.

Table I. Measurements carried out.

	Measured item (WHAT)	Measurement method (HOW)	Measurement time (WHEN)
Physiological measurements	Blood pressure	Wrist blood pressure monitor	Before and after each work session
	Heart rate	Wrist blood pressure monitor	Before and after each work session
	Body temperature	Ear thermometer	Before and after each work session
	Physical activity	Pedometer	For the whole day
	Sleep quality	Pedometer	Every night
Psychological measurements	Mood	EVEA test	Before and after each work session
	Perception of space	SAP Questionnaire	Before and after each work session
	Stress	PSS test	At the beginning and at the end of the experiment
	Sleep habits	CHAS test	At the beginning and at the end of the experiment
	Habits of physical exercise	IPAQ test	At the beginning and at the end of the experiment
Productivity measurements	Cognitive capacity related to memory	Exercises developed by the University of	Twice a day, in morning and afternoon session
	Cognitive ability related to verbal ability	Cambridge in its Brain Science Lab	
	Cognitive ability related to reasoning		

Creativity measurements	Generation of simple and complex ideas to solve problems	Taxonomy Method of Creative Thinking	Twice a day, in morning and afternoon session
Environmental Measurements	Illuminance	Luxmeter	Every 15 minutes
	Noise	Sound level meter	during work sessions
	CO ₂ concentration	Environmental measuring station	Continuous every day
	Temperature		
	Relative Humidity		

3.4. Pilot Experiment Assessment.

The pilot experiment was carried out in three different locations. To use the same nomenclature as in the state of the art, the reference of A.H. Maslow was taken and the three types of spaces were called “Ugly” office “Average” office, and “Beautiful” office [95].

As Figure 1 shows, the total duration of the pilot experiment was 10 days.

Figure 1. Schedule.

The study group was characterized as follows: the subjects were eight men and six women, with an age between 20 and 26 years, a similar cultural and socio-economic level.

The 14 subjects were divided into four groups that combine the different variables to be measured: training through change management, physical exercise and meditation, and the combined action of the two previous ones (Table II).

Table II. Distribution of the four groups. All the groups follow the same path of Ugly, Optimum and Beautiful office.

Group	Variables	Number of participants
GROUP A	BENCHMARK (without variables)	3 people
GROUP B	PHYSICAL EXERCISE AND MEDITATION	3 people
GROUP C	TRAINING TROUGH CHANGE MANAGEMENT	4 people
GROUP D	PHYSICAL EXERCISE AND MEDITATION + TRAINING TROUGH CHANGE MANAGEMENT	4 people

Beautiful	Average	Ugly
Encourages teamwork, relationships and employee welfare It has the most advanced standards of efficiency and innovation and is aligned with the corporate culture	Encourages the completion of work It has the appropriate technology, although it could probably be designed more aligned with the corporate culture and promoting well-being	Assigned workstations It does not favor collaborative work Misused surface It does not have the adequate technology and it does not allow to optimize the processes

In this pilot experiment, the subjects carried out simulated work series, with four sets in the morning session and four in the afternoon (Figure 2).

The pilot experiment daily schedule is shown in Figure 2. The subjects arrived at the office at 10 a.m. First, they answered a questionnaire about their activities the day before. After that, they begun a 60-minute session, with physiological measurements, questionnaires and performing simulated work.

Before and after the pilot experiment, subjects had free time. However, strenuous exercise or consumption of alcohol were prohibited.

It has been shown that performance decreases as the task comes to an end. Therefore, with the aim of not compromising the results of the task sets one and two, a third set of tasks was added whose results were not considered, thus eliminating the "end time effect" [35].

Figure 2. Daily schedule

Table III shows the configuration of the pilot experiment combining twelve Scenarios. Each Scenario combines the type of workplace and the activities carried out.

Table III: Pilot Experiment configuration combining twelve Scenarios. Each Scenario combines as variables: type of space, training through change management, physical exercise and meditation.

		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
GROUP A	Subject 1	SCENARIO 1: Ugly	SCENARIO 5:	SCENARIO 5:	SCENARIO 9:	SCENARIO 9:
	Subject 2	space. Benchmark	Average space.	Average space.	Beautiful space.	Beautiful space.
	Subject 3	group	Benchmark group	Benchmark group	Benchmark group	Benchmark group
GROUP B	Subject 4	SCENARIO 2: Ugly	SCENARIO 6:	SCENARIO 6:	SCENARIO 10:	SCENARIO 10:
	Subject 5	space. Physical	Average space.	Average space.	Beautiful space	Beautiful space
	Subject 6	exercise and meditation.	Physical exercise and meditation.	Physical exercise and meditation.	Physical exercise and meditation.	Physical exercise and meditation.
GROUP C	Subject 7	SCENARIO 3: Ugly	SCENARIO 7:	SCENARIO 7:	SCENARIO 11:	SCENARIO 11:
	Subject 8	space. Training	Average space.	Average space.	Beautiful space	Beautiful space
	Subject 9	trough change	Training trough	Training trough	Training trough	Training trough
	Subject 10	management	change management	change management	change management	change management
GROUP D	Subject 11	SCENARIO 4: Ugly	SCENARIO 8:	SCENARIO 8:	SCENARIO 12:	SCENARIO 12:
	Subject 12	space. Physical	Average space.	Average space.	Beautiful space	Beautiful space
	Subject 13	exercise and	Physical exercise	Physical exercise	Physical exercise	Physical exercise
	Subject 14	meditation and training trough change management	and meditation and training trough change management	and meditation and training trough change management	and meditation and training trough change management	and meditation and training trough change management

3.4.1. Environmental assessment.

Throughout the pilot experiment, according to the ASHRAE 55 standard [3], indoor temperature, humidity, air velocity, CO₂ concentration, lighting and noise level were measured with four environmental measurement stations.

According to the ASHRAE 55 standard, the air renewal during the tests was 0.3 liters per second per cubic meter.

A continuous measurement of the ambient temperature, relative humidity and CO₂ was carried out. In the same way, noise and lighting on the work surface were measured at 15-minute intervals.

According to the regulations of the Spanish Technical Code, the interior of the office was in standard conditions. Table IV shows the average values obtained.

Table IV: Results of the internal environmental measurement during the pilot experiment ($\pm$ Standard Deviation).

	Morning			Afternoon		
	UGLY	AVERAGE	BEAUTIFUL	UGLY	AVERAGE	BEAUTIFUL
Temperature [°C]	22.19 $\pm$ 0.5	23.78 $\pm$ 0.5	24.14 $\pm$ 0.5	23.13 $\pm$ 0.5	25.07 $\pm$ 0.5	24.50 $\pm$ 0.5
HR [%]	52.09 $\pm$ 2.0	38.04 $\pm$ 2.0	33.50 $\pm$ 2.0	49.59 $\pm$ 2.0	36.00 $\pm$ 2.0	35.60 $\pm$ 2.0
CO ₂ [ppm]	3228.69 $\pm$ 10	881.46 $\pm$ 11	716.34 $\pm$ 11	3013.95 $\pm$ 10	843.43 $\pm$ 11	701.43 $\pm$ 11
	9	1	2	9	1	2
Noise [dB]	33.38 $\pm$ 1.2	30.49 $\pm$ 1.5	26.41 $\pm$ 1.4	32.63 $\pm$ 1.2	31.47 $\pm$ 1.5	26.42 $\pm$ 1.4
Illuminance in the horizontal plan [lx]	376.07 $\pm$ 8	719.82 $\pm$ 10	790.23 $\pm$ 11	485.05 $\pm$ 8	745.68 $\pm$ 10	825.16 $\pm$ 11

3.4.2. Physiological assessment.

The physiological information, composed of physical activity, body temperature, blood pressure, and heart rate was measured in the time intervals shown in Figure 3.

Figure 3. Programming of physiological and psychological samples (it is repeated in the 3 work sessions).

3.4.3. Psychological assessment.

The analysis of psychological parameters was carried out through questionnaires, which together provide a holistic view of the subjective perception of the subjects, from the point of view of the perception of space, the perception of the subjective physical state and the subjective perception of the workload.

Subsequently, the analysis of the correlation between physiological and psychological parameters allowed to objectify the latter.

METHOD THROUGH QUESTIONNAIRE. SCREENING TEST SA-45.

The Spanish version of the Symptom Assessment Questionnaire (SA-45), of Davison, MK, Bershadsky, B., Bieber, J., Silversmith, D., Maruish, ME, and Kane, was used. RL in 1997 [28].

It served as a screening tool for any possible psychopathological disorder. It consists of 45 items derived from the SCL-90, and nine scales of five items each that evaluate the same dimensions as the SCL-90 (depression, hostility, interpersonal sensitivity, somatization, anxiety, psychoticism, obsession-compulsion, phobic anxiety and paranoid ideation).

METHOD THROUGH QUESTIONNAIRE. PERCEIVED STRESS SCALE TEST PSS.

The participants were evaluated by the Spanish version of the Perceived Stress Scale (PSS), by Cohen, S., Kamarck, T., & Mermelstein, R. in 1983, It demonstrated adequate reliability (internal consistency and test-retest), validity (concurrent) and sensitivity [24].

It consists in fourteen items with a response format of a scale of five points (0 = never, 1 = almost never, 2 = occasionally, 3 = often, 4 = very often), which evaluate how often the participant had stressful thoughts and feelings during the last month.

METHOD THROUGH QUESTIONNAIRE. SLEEPING HABITS QUESTIONNAIRE (CHAS).

Sleep habits were evaluated through the Sleep Habits Questionnaire (CHAS) developed by Dr. Díaz Ramiro and Dr. Rubio Valdehita in 2013 [33].

This questionnaire consists of 30 items that assess sleep habits at the current time of the participant through a likert scale (where one represents that the subject is in "total disagreement" with the statement and five in "total agreement").

It evaluates three dimensions: quality of sleep, stability in sleep habits and daytime sleepiness. Their convergent validity and reliability indexes are acceptable.

It is a questionnaire of easy administration developed to know the sleep habits in normal population.

METHOD THROUGH QUESTIONNAIRE. INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (IPAQ).

The short version of IPAQ, asks about three types of activity. The specific types of activity are "walking", "moderate intensity activities" and "vigorous intensity activities".

The items in the short version are structured to provide separate results for the three types of "walking" activity, "moderate intensity activities" and "vigorous intensity activities".

Obtaining the result for the short version requires the addition of the duration (in minutes) and the frequency (days) of these three types [32].

METHOD THROUGH QUESTIONNAIRE. SUBJECTIVE ASSESSMENT OF WORKPLACE PERFORMANCE (SAP).

The participants completed the questionnaire to analyze the environmental influence in the building, both the perception of comfort and intellectual performance.

This survey has been studied in the Sustainable Construction Association of Japan, the Institute of Architecture of Japan, the Society of Engineering of Air Conditioning and Sanitation [78].

The degree of satisfaction with the interior environment was evaluated on a scale of six degrees: thermal comfort, light, noise, air quality and spatial environment both in the workplace and in the rest area [136], [143], [148], [184].

METHOD THROUGH QUESTIONNAIRE. MOOD RATING SCALE QUESTIONNAIRE (EVEA).

The EVEA questionnaire was constructed as an instrument to measure transient moods in studies that use mood induction procedures [134].

EVEA consists of sixteen items, each composed of a liker-type graphic scale of eleven points (from 0 to 10), flanked by the words "nothing" (0) and "much" (10), which it presents in its left margin a short statement that describes a state of mind.

The sixteen sentences have the same construction; they all start with the words "I feel" and continue with an adjective that represents a state of mind (i.e. "I feel sad", "I feel happy").

EVEA aims to evaluate four moods: anxiety, anger-hostility, sadness-depression and joy. Each state of mind is represented by four items with different adjectives which define a subscale, and all the items within each subscale are formulated in the same direction.

3.4.4. Productivity Evaluation through Cognitive Capacity.

Three generic cognitive skills were tested: memory, concentration and reasoning. Two short cognitive performance tests were selected online for each skill.

The six tests used in this study (Figure 4) come from the public website of Cambridge Brain Sciences (CBS) and were based on classic paradigms of the cognitive psychology literature.

For memory ability, the Digit Span task tests the verbal memory of the subjects by remembering a sequence of numbers that appear on the screen one after the other; the Spatial Span task tests the visuospatial memory of the subjects by remembering a sequence of blinking boxes that appear on the screen one after the other.

For concentration ability, the Rotations test is used to measure the mental rotation skills of the subjects, while the Feature Match test combines the attention processing of the subjects by comparing features of several images in different ways and indicating whether the contents are identical.

In reasoning skills, the Odd One Out task requires participants to determine which of the nine patterns is the odd; the Grammatical Reasoning task requires participants to indicate whether a statement correctly describes a pair of objects that are displayed in the center of the screen.

Figure 4. Tests to evaluate the cognitive capacity for each skill

3.4.5. Evaluation of Creativity through the Taxonomy Method of Creative Thinking.

Since creative work can be measured along the spectrums of form and content, the Taxonomy of Creativity Thought offered a progression from imitation to original creation measured in terms of form and content.

In doing so, it organized creative works in an inclusive and unifying landscape that serves as an analytical lens through which creative work can be evaluated [146].

3.4.6. Physical Exercise and Meditation.

A high impact neurocellular training model was proposed. It combined meditation as a technique to achieve maximum performance and muscle training as a technique to fix it in the self.

Until now, training techniques were always based on progressively improved technical knowledge. Occasionally a new concept appeared, but it was always framed within a very clear field that was the physical part or muscular work. On the other hand, and separately, appeared the part of meditation, which was confused with relaxation or mental evasion.

In this pilot experiment, a training was used that is in the exact place of balance, which allowed the training to work naturally, like the act of breathing.

3.4.7. Workplace training: change management.

The processes of corporate transformation that involve changes in work environments, forms of work and / or new location of corporate headquarters can have complex acceptance among the various groups of the company.

To achieve the commitment and involvement of employees with the new situation of their work environment, activities were planned to promote knowledge of the proposed new model workspace.

A tailored strategy was designed to the pilot experiment. In this Scenario, as it was a short period of time, two workshops were designed through which the subjects involved could know and become familiar with the environment where they were going to develop their journey and understand what each of the spaces was designed for, with the intention that they knew the office better and what they could offer them.

The first space used, corresponding to the Ugly office, did not need training. In the second space, Average Office, the workshop focused on explaining the work model, based on flexibility and free movement through space.

Each space was shown explaining what they were created for and the provision of both furniture and technology available to each one, which allows selecting the best space for each of the activities that they had to develop.

In the next space they used, Beautiful office, the new spaces were explained, highlighting the differences that exist with the Average office.

However, the focus was on the subjects knowing the benefits of this environment, which has a wellness certification [71] and therefore its design is based on taking care of the health of the people, making available a series of elements that encourage physical activity and follows wellness strategies.

Both workshops were prepared with a part of explanation and interaction with the participants and an explanation for each of the spaces so that the subjects could test them and solve their doubts both of their own environment and of the work model, based on the activity, which I had proposed them.

The objective of this training was for the subjects to gain confidence in the use of the environment, to be participatory and to be more involved in their activity.

3.4.8. Statistical Methods.

To determine if there are statistically significant differences between the means of two or more independent groups, it is possible to use the method of Analysis of Variance (ANOVA).

The ANOVA method is also known as ANOVA between subjects or one-way ANOVA. Although it can be used with an independent variable with only two groups, in that Scenario it is more usual to use the t test.

For this reason, the ANOVA method is used as a test to use when you have three or more groups (instead of two or more groups).

It is important to note that ANOVA is an omnibus statistical test and cannot identify which specific groups were significantly different from each other; It just says that at least two groups were different.

When there are three, four, five or more groups in the study design, it is important to determine which of these groups differ from each other. This is done using follow-up tests, which will be a post hoc test or tests of personalized contrasts.

Figure 5 and table V show how the ANOVA method is used to analyze the results of three different types of variables in the study: (a) to determine if there are differences between three independent variables; (b) determine if there are differences between two strategies; and (c) determine if there are differences in the resulting productivity scores.

Figure 5. Flow diagram of the application of the ANOVA method in the design of the experiment

Table V. Dependent and independent variables used in the ANOVA method.

	DEPENDENT VARIABLE	INDEPENDENT VARIABLES		
		Name	Groups' number	Groups' name
Is there any difference in productivity increase between the three types of offices?	Cambridge Brain Science test results	Office design	3	Group 1: Ugly office Group 2: Average office Group 3: Beautiful office

3.5. Results and discussion.

Due to reasons of confidentiality and industrial exploitation, the detail of the measurements made in this Case Study have been omitted.

IMPROVEMENT IN PRODUCTIVITY.

The results of the tests related to cognitive ability provided by Brain Science Cambridge are analyzed.

To eliminate individual differences in capacity, the results obtained are normalized and analyzed. Additionally, the results of the training session held on the first day are eliminated, considering the effect of inexperience [119].

In the analysis of the relationship between the three different types of offices with productivity results, a statistical analysis is performed through the one-way ANOVA method. First, the results are identified outside the normal distribution, as shown in Figure 6.

One result is detected outside the normal distribution, and two extreme results. It is confirmed that one of the subjects presents abnormal productivity results, eliminating the two extreme samples from the analysis.

Figure 6. Analysis of normal distribution of productivity results. There are three values outside the normal distribution, two of which are extreme.

After eliminating the extreme values, and given that it is a pilot experiment the sample is reduced, we proceed to perform the Shapiro-Wilk test to confirm that the samples have a normal distribution.

Table VI. Saphiro-Wilk test results.

	Type of office	Shapiro-Wilk Test
Productivity results	UGLY	0,955
	AVERAGE	0,099
	BEAUTIFUL	0,845

Table VI shows that the productivity results of the Cambridge Brain Science were normally distributed for the groups of the Ugly office, Optimum office and Beautiful office, as established by the Saphiro-Wilk test ($p > 0.05$).

The ANOVA analysis data are shown in Table VII as mean $\pm$ standard deviation. The productivity results (Cambridge Brain Science tests) increased from the Ugly office ($n = 28$; 49.7 ± 0.2), to the Average office ($n = 56$; 50 ± 1.2), to the Beautiful office ($n = 54$; 50.2 ± 0.1), in that order.

Table VII. ANOVA Analysis

	N	AVERAGE	STANDARD DEVIATION	ERROR DEVIATION	95 of the confidence interval for the average		MINIMUM	MAXIMUM
					LOWER	UPPER		
					LIMIT	LIMIT		
UGLY OFFICE	28	49,6660	0,16106	0,03044	49,6036	49,7285	49,33	49,98
AVERAGE OFFICE	56	49,9716	0,15693	0,02097	49,9296	50,0136	49,70	50,33
BEAUTIFUL OFFICE	54	50,1996	0,13483	0,01835	50,1628	50,2364	49,79	50,50
TOTAL	138	49,9988	0,24669	0,02100	49,9573	50,0403	49,33	50,50

Table VIII shows that there was homogeneity of variances, as evaluated by the Levene test for equality of variances ($p = 0.357 > 0.05$).

Table VIII. Levene Test

	Statistic of Levene	gl1	gl2	Significance
It is based on the average	1,037	2	135	0,357
It is based on the median	0,886	2	135	0,414
It is based on the median and with adjusted gl	0,886	2	132,488	0,415
It is based on the cropped media	1,019	2	135	0,364

The productivity results were significantly statistically different for the three office types $F(2; 135) = 118.96$; $p < 0.0005$.

In conclusion, an ANOVA analysis was carried out to determine if the productivity was different for the groups in different types of offices. The participants were classified into three groups: Ugly office ($n = 28$), Average type office ($n = 56$), and Beautiful type office ($n = 54$).

There were two extreme atypical values that were eliminated, as evaluated by the analysis of normal distribution; the data were normally distributed for each group, as assessed by the Shapiro-Wilk test ($p > 0.05$); and there was homogeneity of variances, as evaluated by the Levene variance homogeneity test ($p = 0.357 > 0.05$).

The data are presented as mean $\pm$ standard deviation. There was a statistically significant difference in the score between the different office spaces $F(2; 135) = 118.96$, $p < 0.0005$.

The productivity score increased from the Ugly office ($n = 28$, 49.7 ± 0.2), to the Average office ($n = 56$, 50 ± 1.2), to the Beautiful office ($n = 54$, 50.2 ± 0.1), in that order.

Tukey-Kramer post hoc analysis revealed that the increase from Ugly to Optimum (0.31, 95% CI (0.22 to 0.39)) was statistically significant ($p < 0.05$), as well as the increase in Ugly to Beautiful (0.53, 95% CI (0.45 to 0.61), $p < 0.05$), and the increase from Average to Beautiful (0.23, 95% CI (0.16 to 0.30), $p < 0.05$).

A statistical analysis is performed through the ANOVA method of a factor of the relationship between the four groups and the productivity results. First, the results are identified outside the normal distribution, eliminating samples 1 and 64, belonging to group 2.

The participants were classified into four groups in this second analysis: control group ($n = 22$), group that performed physical exercise and meditation ($n = 26$), group that receives training in change management ($n = 40$), and group that performs physical exercise and meditation and receives training in change management ($n = 36$).

There were two extreme atypical values that were eliminated, as evaluated by the analysis of normal distribution; the data were normally distributed for each group, as assessed by the Shapiro-Wilk test ($p > 0.05$); and the homogeneity of variances was violated, as assessed by the Levene variance homogeneity test ($p = 0.028 < 0.05$).

Due to this result, the contrasts between groups were studied, but the difference between groups was not statistically significant, $F(3, 120) = 0.223$, $p = 0.880$.

Next, we study the results of increased productivity by combining groups and types of office spaces.

Figure 7 shows that productivity in the Average office was 34.58% ($p < 0.05$) higher compared to the Ugly office, and in the Beautiful office it was 62.15% ($p < 0.05$) higher than in the Ugly office.

Figure 8 shows the results of productivity improvement by activities carried out, increasing productivity by 15% ($p < 0.05$) in the group that exercised and mindfulness and by 15.05% ($p < 0.05$.) in the group that had training in change management, with respect to the control group.

Figure 9 shows the results when combining the change of space with the realization of activities, highlighting the increase in productivity by 63,34% ($p < 0.05$) in the Scenario of the group that occupies the office Beautiful, performs physical exercise and mindfulness and receives training in change management.

Figure 7. Results of productivity improvement by type of office. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

Figure 8. Results of productivity improvement by activities carried out. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

Figure 9. Results of productivity improvement by type of office and activities carried out. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

IMPROVEMENT IN CREATIVITY.

Creativity, measured by the taxonomy method of creative thinking, increases by 144.01% ($p < 0.05$) in the Average office scenario, compared to the Ugly office (Figure 11). If we distinguish between the complexity of generating ideas,

Figures 12 and 13 show an increase in the generation of simple ideas of 72.09% ($p < 0.05$) and an increase in the generation of complex ideas of 452.17% ($p < 0.05$) in the Average office.

However, when we combine space, physical exercise and meditation, and training in change management, Figure 10 shows that the best result occurs in the Beautiful office, with an increase in creativity of 137.50% ($p < 0.05$).

Likewise, Figure 11 shows that only with training in change management there is an increase in creativity of 100.46% ($p < 0.05$) with respect to the control group. From the analysis of these results and the correlation with the physiological and psychological measurements, it is deduced that a Beautiful office, if not accompanied by an adequate management, does not produce the expected impact in the increase of creativity.

Figure 10. Results of improvement of creativity by type of office: number of ideas generated. Measurement based on the taxonomy of creative thinking.

Figure 11. Results of improvement of creativity by type of office: improvement of generation of simple ideas (brainstorming). Measurement based on the taxonomy of creative thinking.

Figure 12. Results of improvement of creativity by type of office: improvement of generation of complex ideas (innovation). Measurement based on the taxonomy of creative thinking.

Figure13. Results of improvement of creativity by type of office and by activities carried out. Measurement based on the taxonomy of creative thinking.

Figure 14. Results of improvement of creativity by activities carried out. Measurement based on the taxonomy of creative thinking.

IMPROVEMENT IN MOTIVATION.

It is necessary to consider the starting situation of the sample of subjects to assess the results of motivation.

According to the psycho-social study carried out, the sample presents a general result of dysphoric mood characterized by lack of motivation, hopeless feelings about the future, loneliness and sadness.

Therefore, it is convenient to assess the result in relative terms of comparison, and never in absolute terms. Thus, it is worth highlighting the increase in motivation that occurs in the situation of subjects who receive training in change management and perform physical exercise and meditation, in the setting of the Beautiful office, being 4.59% higher than the control group in the same type of office.

Likewise, the motivation of the control group, which does not carry out activity or receive training, decreases in a similar proportion, -4.08%, in the same Beautiful office scenario.

We can conclude that the activities carried out (training and exercise) are key in the increase of motivation.

Figure 15. Results of improvement of subjective motivation for activities carried out and types of space.

IMPROVEMENT IN SLEEP QUALITY.

The quality of the sleep, measured through a pedometer that each subject took along the execution of the pilot experiment, increases in the Average office setting.

However, the difference between groups of activities (exercise and change management training) did not have a significant impact.

Figure 16. Results of improvement of sleep quality score.

Figure 17. Results of increased duration of deep sleep.

IMPROVEMENT IN COMFORT.

Well-being measured in environmental parameters such as temperature, humidity, air quality, acoustics, lighting and space amplitude increased 12.30% in office users Beautiful.

Figure 18. Results of improvement of subjective well-being.

IMPROVEMENT IN THE CAPACITY OF ATTENTION.

The relationship between the Low Frequency Sympathetic Activity (LF) and the High Frequency (HF) Activity during the work sessions between the different groups is analyzed.

The difference of the resting value of each day for each subject is calculated and taken as a relative value to eliminate the individual differences between days.

In addition, samples in which the resting sympathetic state is abnormal are excluded. It is believed that it is desirable for the sympathetic nervous system to be active and alert during work [115].

As shown in Figure 19, in the morning session the sympathetic activity is 0.012 points higher ($p < 0.05$) after physical exercise and meditation, compared to the control group, which experienced a decrease of 0.012 points ($p < 0.05$).

Likewise, Figure 20 shows that in the afternoon session the sympathetic activity is 0.01 points higher ($p < 0.05$) after performing physical exercise and meditation, in comparison with the control group, which experiences a decrease in 0.02 points ($p < 0.05$).

From this, it is shown that the realization of physical exercise and meditation in the working day could activate the sympathetic nervous system during work, causing an Average state.

Figure 19. Activity of the sympathetic nervous system in the morning. Comparison between the group that performs physical exercise and meditation with the control group.

Figure 20. Activity of the sympathetic nervous system in the afternoon. Comparison between the group that performs physical exercise and meditation with the control group.

3.6. Conclusions.

The main results obtained can be summarized as follows:

- Productivity increases 62.14% in the office BEAUTIFUL.
- Productivity increases by 15.15% when doing physical exercise and meditation.
- Productivity increases by 15% when receiving workplace training.
- Productivity increases by 63.34% when we combine BEAUTIFUL office, workplace training and physical exercise and meditation.
- Creativity increases by 144.01% in the office BEAUTIFUL, measured amount of ideas generated according to the taxonomy method of creative thinking.
- Creativity increases by 232.51% when we combine the BEAUTIFUL office with workplace training.
- Creativity increases by 100.46%, including workplace training.
- Motivation increases by 4.59% when we combine the BEAUTIFUL office with workplace training and physical exercise and meditation.
- The quality of sleep increases 18 points in the AVERAGE office users.
- AVERAGE office users enjoy an average of 18.86 minutes of restful deep sleep every night.
- Well-being measured in environmental parameters such as temperature, humidity, air quality, acoustics, lighting and spaciousness increased 12.30% in office users BEAUTIFUL.
- It is believed that it is desirable for the sympathetic nervous system to be active and alert during work. The activity of the sympathetic nervous system increased 0.011 points in the people who performed physical exercise and meditation.

C.V. CONCLUSIONES

Este capítulo recoge las conclusiones generales del presente documento de Tesis, que se divide en dos partes. Por una parte, análisis e interpretación de los resultados; por otra parte, conclusiones relacionadas con la hipótesis de Tesis.

Por último, se apuntan lecciones aprendidas para la de optimización de la Herramienta, y futuras líneas de investigación

1. ANÁLISIS E INTERPRETACIÓN DE LOS RESULTADOS

El Estado del Arte de esta Tesis Doctoral establece una clara tendencia a oficinas sostenibles, con la creencia de que éstas aumentarán la productividad de las personas. Sin embargo, hasta ahora no había sido posible medir cuánto es este aumento. En respuesta a esta necesidad, surge la Herramienta desarrollada en esta investigación, que permite cuantificar el impacto de los entornos de trabajo en el aumento del bienestar y la productividad de las personas.

La herramienta probada con los tres experimentos piloto realizados permite cuantificar la influencia de algunas variables en el bienestar y la productividad en el espacio de trabajo, lo cual proporciona un mayor conocimiento de los conceptos productividad y la creatividad en entornos de trabajo, y cómo podría ser mejorado.

Los resultados obtenidos en los experimentos piloto apuntan a beneficios adicionales para la productividad, la creatividad, el bienestar del usuario y la salud en los espacios de trabajo diseñados con criterios de Biofilia. En general, los participantes reportaron mejores resultados en tareas creativas, mejores percepciones ambientales y menos síntomas en el espacio biofílico respecto a aquellos que ocuparon el escenario de control.

Los hallazgos sugieren que los beneficios cuantificables del lugar de trabajo biofílico van más allá de los indicadores fisiológicos medibles. Las variables estudiadas pueden jugar un papel importante en la salud y la función cognitiva de los ocupantes, y ambos podrían evaluarse a través de la medición de parámetros subjetivos y objetivos.

Por lo tanto, la primera conclusión general extraída del análisis en conjunto de los tres casos de estudio presentados, es que las variables relativas a diseño biofílico se relacionan con un peor resultado en tareas no creativas o repetitivas, como la tarea de mecanografiado (Figura 1).

Sin embargo, esas mismas variables se relacionan con mejores resultados en tareas creativas, como la realización de mapas mentales (Figura 2). De esta manera, a partir de los resultados obtenidos es posible afirmar que el diseño biofílico en espacios de trabajo aumenta la creatividad de los usuarios.

Figura 1. Recopilación de resultados obtenidos en los tres casos de estudio en tareas no creativas

Figura 2. Recopilación de resultados obtenidos en los tres casos de estudio en tareas no creativas

La segunda conclusión señala la relación de las variables vinculadas al diseño biofílico con un impacto en los parámetros fisiológicos de las personas.

Por un lado, los grupos bajo la influencia de estas variables presentan en todos los casos niveles inferiores de concentración de enzima amilasa en saliva, la cual se relaciona con un menor nivel de estrés de las personas (Figura 3).

Por otro lado, los grupos que usaron los escenarios con variables de diseño biofílico presentan una mayor actividad en su sistema nervioso autónomo, lo cual se relaciona con una mayor capacidad de atención durante el trabajo (Figura 4).

Figura 3. Recopilación de resultados en los diversos casos de estudio que muestran una menor concentración de enzima amilasa en saliva en los grupos que usaron espacios de diseño biofílico

Figura 4. Recopilación de resultados en los diversos casos de estudio que muestran una mayor actividad del sistema nervioso autónomo en los grupos que usaron espacios de diseño biofílico

Anteriormente se ha comentado el impacto de las variables relacionadas con el diseño biofílico, entendidas como aspectos tangibles, tales como presencia de vegetación, luz natural o acabados en madera.

Sin embargo, la tercera conclusión principal en el análisis conjunto de los tres casos de estudio se relaciona con la variable intangible de formación a través de la gestión del cambio, definida como la información y talleres que se prestan a los usuarios para facilitar que obtengan el mayor potencial de un entorno adaptado a los nuevos modos de trabajar, así como información sobre el impacto positivo que un entorno diseñado bajo criterios de Biofilia tiene en su salud.

Cuando los resultados en creatividad son analizados en su conjunto sólo teniendo en cuenta las variables tangibles, se ven afectados en una proporción similar por los espacios de diseño biofílico, tal como muestran la Figura 2 del presente capítulo.

Sin embargo, cuando los resultados de creatividad se combinan con la variable intangible en formación a través de la gestión del cambio, se observa una mejor puntuación en ambos casos entre los grupos impactados por esta variable (Figura 5).

Por otro lado, la variable intangible de formación a través del cambio presenta un resultado notable en su impacto en los niveles de motivación, que en gestión contemporánea de recursos humanos se relaciona con una mayor capacidad de retención y atracción de talento (Figura 6).

Figura 5. Mejores resultados de creatividad en el grupo que recibe formación a través de la gestión del cambio

Figura 6. Impacto en el resultado en motivación en el grupo que recibe formación a través de la gestión del cambio

Según el Centro para Control y Prevención de Enfermedades de Estados Unidos, la mala higiene del sueño es el principal problema de salud entre los americanos, por delante de problemas como el tabaquismo, alcoholismo, sedentarismo y obesidad [47].

Se observa un impacto notable en la mejor calidad del sueño de los sujetos participantes que ocuparon los escenarios con acabados de madera natural (Figura 7).

Figura 7. Resultados de calidad del sueño comparando Caso 1 (grupo de control) y Caso 3 (grupo bajo la influencia de acabados de madera natural).

Como ultima conclusión dentro de este análisis conjunto de los tres casos de estudio presentados, se puede afirmar a partir de los resultados obtenidos que no existe una receta única de espacio ideal para todos los casos.

Sobre la base del experimento piloto realizado, es posible resumir el procedimiento utilizado, que se presenta en este artículo, y se compone de tres fases.

La fase uno consistió en llevar a cabo trabajos previos, que incluyeron la recopilación de sujetos experimentales, la selección de los parámetros que se medirían, la creación de escenarios que combinan estos parámetros, la selección de las pruebas que se realizarán y la definición del alcance y el cronograma del estudio de acuerdo con los objetivos establecidos previamente.

La fase dos de la herramienta consistió en ejecutar el experimento piloto, que permitió la recolección de un número suficiente de muestras, que se analizaron en la fase tres.

Después de la fase tres, se obtuvieron los resultados, que servirán para mejorar un futuro estudio en profundidad.

Sobre la base de la aplicación de esta herramienta en el estudio de caso, que se presenta en este artículo, se aprendieron varias lecciones (Figura 8). El principal fue el retorno positivo de invertir suficiente tiempo y recursos en la fase uno.

Dado que un diseño adecuado de los escenarios del experimento piloto es clave para su éxito, al definir exactamente las variables a medir, hubiera sido conveniente definir los atributos de la luz del día con más detalle.

Figura 8. Lecciones aprendidas en las tres fases que componen la herramienta

2.CONCLUSIÓN FINAL

MEDIANTE LA REALIZACIÓN DE EXPERIMENTOS PILOTO SE DEMUESTRA QUE ESTA HERRAMIENTA PERMITE MEDIR, Y POR TANTO MEJORAR, LA PRODUCTIVIDAD Y BIENESTAR DE LOS USUARIOS EN LOS ESPACIOS DE TRABAJO CON MÚLTIPLES VARIABLES QUE PUEDEN SER CARACTERIZADAS, Y ABRE NUEVAS FORMAS DE MEDIR LAS CAPACIDADES EN EL LUGAR DE TRABAJO, FOMENTANDO LOS FACTORES CLAVE PARA MEJORAR EL DESEMPEÑO DE LOS FACILITY MANAGERS.

Ha quedado demostrado a través de la metodología de investigación que la hipótesis era cierta:

- Una herramienta adecuada puede permitir medir, y por tanto mejorar, la productividad y bienestar de los usuarios en los espacios de trabajo con múltiples variables que pueden ser caracterizadas.

El objetivo inicialmente planteado se ha alcanzado:

- Desarrollar una herramienta que nos permita medir de manera objetiva la mejora de productividad y bienestar en entornos de trabajo.

Asimismo, los objetivos secundarios se consiguen:

- Identificadas qué variables tienen un mayor impacto en la experiencia del usuario: se demuestra que el impacto de variables combinadas, tanto tangibles como intangibles, es mayor que el impacto sumado de diversas variables aisladas.
- Analizados específicamente los resultados del impacto en la calidad del sueño.

- Analizado el efecto psicológico de algunas variables, que no tienen un efecto real pero sí percibido: en idénticas condiciones ambientales, la satisfacción con el entorno aumenta ante la presencia de variables biofílicas.

3. OPTIMIZACIÓN DE LA HERRAMIENTA Y FUTURAS LÍNEAS DE INVESTIGACIÓN

Esta Tesis Doctoral descubre un nuevo campo por explorar, que ha sido previamente señalado en el Estado del Arte.

Existe una clara tendencia que apunta a que los espacios de trabajo diseñados según criterios de sostenibilidad y Biofilia hacen que aumente la productividad y el bienestar de las personas, pero hasta ahora no era posible saber cuánto.

La Herramienta propuesta en esta Tesis da respuesta a esta necesidad. El desarrollo de la misma y su aplicación en tres casos de estudio, devuelven unas lecciones aprendidas en cuanto a cómo sería posible optimizar dicha Herramienta:

- La Herramienta necesita de un trabajo personal y a medida, por lo que una mejora en su automatización permitiría la sistematización de la Herramienta mediante el uso de herramientas informáticas.
- Los casos de estudio utilizados para comprobar la Herramienta consisten en experimentos piloto. El siguiente paso consistiría en la realización de un estudio mayor, que permitiría ampliar la Herramienta añadiendo un paso más allá de los experimentos piloto.
- Ampliar el alcance de los experimentos piloto permitiría disponer de un mayor número de muestras, lo cual redundaría en resultados más precisos.

Asimismo, queda mucho por estudiar en esta área, mejorar optimizar y calcular retornos de inversión en estos y otros escenarios. En este sentido, algunas de las futuras líneas de investigación podrían ser:

- Aplicación a otro tipo de activos inmobiliarios además de oficinas: comercial, residencial, sanitario, etc.
- A partir de medir la mejora de la productividad cuantificada, se podría analizar la repercusión económica para las empresas calculando el retorno de la inversión en entornos de trabajo enfocados a aumentar el bienestar de las personas.
- Todo escenario creado en los casos de estudio presentados se trata de espacios interiores. Una línea de investigación futura sería añadir nuevos escenarios experimentales no interiores.

C.V. CONCLUSIONS

This chapter contains the general conclusions of this Thesis document, which is divided into two parts. On the one hand, analysis and interpretation of the results; on the other hand, conclusions related to the Thesis hypothesis.

Finally, lessons learned are noted for the optimization of the Tool, and future lines of research.

1. ANALYSIS AND INTERPRETATION OF THE RESULTS

The State of the Art of this Doctoral Thesis establishes a clear trend towards sustainable offices, with the belief that these will increase people's productivity. However, until now it had not been possible to measure how much this increase is. In response to this need, the Tool developed in this research arises, which allows quantifying the impact of work environments on the increase of people's well-being and productivity.

The tool tested with the three pilot experiments makes it possible to quantify the influence of some variables on well-being and productivity in the work space, which provides a greater knowledge of productivity concepts and creativity in work environments, and how it could be improved.

The results obtained in the pilot experiments point to additional benefits for productivity, creativity, user welfare and health in workspaces designed with Biophilia criteria. In general, participants reported better results in creative tasks, better environmental perceptions and fewer symptoms in the biophilic space than those who occupied the control scenario.

The findings suggest that the quantifiable benefits of the biophilic workplace go beyond measurable physiological indicators.

The variables studied may play an important role in the health and cognitive function of occupants, and both could be evaluated by measuring subjective and objective parameters.

Therefore, the first general conclusion drawn from the joint analysis of the three Scenario studies presented is that variables related to biophilic design are related to a worse outcome in non-creative or repetitive tasks, such as the typing task (Figure 1).

However, these same variables are related to better results in creative tasks, such as mind mapping (Figure 2). In this way, from the results obtained it is possible to affirm that biophilic design in workspaces increases the creativity of users.

Figure 1. Compilation of results obtained in the three Scenario studies in non-creative tasks

Figure 2. Compilation of results obtained in the three Scenario studies on non-creative tasks

The second conclusion points out the relationship of variables linked to biophilic design with an impact on physiological parameters of people.

On the one hand, the groups under the influence of these variables all present lower levels of amylase enzyme concentration in saliva, which is related to a lower level of stress in people (Figure 3).

On the other hand, the groups that used the scenarios with biophilic design variables present a greater activity in their autonomous nervous system, which is related to a greater attention capacity during work (Figure 4).

Figure 3. Compilation of results in the various Scenario studies showing a lower concentration of the enzyme amylase in saliva in the groups that used biophilic design spaces.

Figure 4. Compilation of results in the various Scenario studies showing increased activity of the autonomic nervous system in groups using biophilic design spaces.

The impact of variables related to biophilic design, understood as tangible aspects, such as the presence of vegetation, natural light or wood finishes, has been previously commented on.

However, the third main conclusion in the joint analysis of the three Scenario studies relates to the intangible variable of training through change management, defined as the information and workshops provided to users to enable them to obtain the greatest potential from an environment adapted to the new ways of working, as well as information on the positive impact that an environment designed under Biophilia criteria has on their health.

When the results in creativity are analyzed only considering the tangible variables, they are affected in a similar proportion by the biophilic design spaces, as shown in Figure 2 of this chapter.

However, when the results of creativity are combined with the intangible variable in formation through change management, a better score is observed in both Scenarios among the groups impacted by this variable (Figure 5).

On the other hand, the intangible variable of training through change presents a notable result in its impact on motivation levels, which in contemporary human resource management is related to a greater capacity to retain and attract talent (Figure 6).

Figure 5. Better results of creativity in the group trained through change management

Figure 6. Impact on Motivation Outcome in the Group Receiving Training through Change Management

According to the U.S. Centers for Disease Control and Prevention, poor sleep hygiene is the leading health problem among Americans, ahead of problems such as smoking, alcoholism, sedentary lifestyles, and obesity [47].

A notable impact is observed in the better quality of sleep of the participating subjects who occupied the stages with natural wood finishes (Figure 7).

Figure 7. Sleep quality results comparing Scenario 1 (control group) and Scenario 3 (group under the influence of natural wood finishes).

As the conclusion of this joint analysis of the three Scenario studies presented, it can be stated from the results obtained that there is no single recipe for ideal space for all Scenarios.

Based on the pilot experiment carried out, it is possible to summarize the procedure used, which is presented in this article, and consists of three phases.

Phase one consisted of carrying out previous work, which included the compilation of experimental subjects, the selection of parameters to be measured, the creation of scenarios combining these parameters, the selection of tests to be performed and the definition of the scope and schedule of the study according to the objectives previously established. hypothesis.

Phase two of the tool consisted of executing the pilot experiment, which allowed the collection of a sufficient number of samples, which were analyzed in phase three. After phase three, the results were obtained, which will serve to improve a future in-depth study. Based on the application of this tool in the Case Study presented in this article, several lessons were learned (Figure 8).

The main one was the positive return of investing sufficient time and resources in phase one.

Since an adequate design of the scenarios of the pilot experiment is key to its success, when defining exactly the variables to be measured, it would have been convenient to define the attributes of daylight in more detail.

Figure 8. Lessons learned in the three phases that make up the tool

2. FINAL CONCLUSION

THROUGH PILOT EXPERIMENTS, IT IS DEMONSTRATED THAT THIS TOOL ALLOWS TO MEASURE, AND THEREFORE IMPROVE, THE PRODUCTIVITY AND WELL-BEING OF USERS IN WORKSPACES WITH MULTIPLE VARIABLES THAT CAN BE CHARACTERIZED, AND OPENS NEW WAYS TO MEASURE THE CAPABILITIES IN THE WORKPLACE, PROMOTING THE KEY FACTORS TO IMPROVE THE PERFORMANCE OF FACILITY MANAGERS.

It has been demonstrated through the research methodology that the hypothesis was true:

- An adequate tool can measure, and therefore improve, the productivity and well-being of users in workspaces with multiple variables that can be characterized.

The initial objective has been achieved:

- To develop a tool that allows us to measure in an objective way the improvement of productivity and well-being in work environments.

Likewise, secondary objectives are achieved:

- Identified which variables have a greater impact on the user experience: it is demonstrated that the impact of combined variables, both tangible and intangible, is greater than the combined impact of several isolated variables.
- Specifically analyzed the results of the impact on sleep quality.
- Analyzed the psychological effect of some variables, which do not have a real but perceived effect: in identical environmental conditions, satisfaction with the environment increases in the presence of biophilic variables.

3.OPTIMIZATION OF THE TOOL AND FUTURE LINES OF RESEARCH

This Doctoral Thesis discovers a new field to explore, which has been previously pointed out in the State of Art. There is a clear trend that workspaces designed according to criteria of sustainability and Biophilia increase productivity and well-being of people, but until now it was not possible to know how much.

The Tool proposed in this Thesis responds to this need. The development of the same and its application in three case studies, return some lessons learned as to how it would be possible to optimize the Tool:

- The Tool needs a personal and tailor-made work, so an improvement in its automation would allow the systematization of the Tool using computer tools.
- The case studies used to test the Tool consist of pilot experiments. The next step would be to carry out a larger study, which would allow the Tool to be extended by adding a step beyond the pilot experiments.
- Extending the scope of the pilot experiments would allow more samples to be available, resulting in more accurate results.

There is also much to study in this area, to improve optimization and to calculate returns on investment in these and other scenarios. In this sense, some of the future lines of research could be:

- Application to other types of real estate assets in addition to offices: commercial, residential, health, etc.
- By measuring the quantified productivity improvement, the economic impact on companies could be analyzed by calculating the return on investment in work environments aimed at increasing people's well-being.
- All scenarios created in the case studies presented are indoor spaces. A future line of research would be to add new non-interior experimental scenarios.

INDICE DE ILUSTRACIONES

CAPITULO I

Figura 1. Mapa de Proceso de desarrollo de la presente investigación

Figura 2. Calendario de Proceso de desarrollo de la presente investigación

CAPITULO II

Figura 1. Panteón en Roma, la primera oficina que se reconoce en la Historia

Figura 2. East India House, primera oficina moderna

Figura 3. El “Antiguo Almirantazgo” (Edificio Ripley), construido en 1726, fue el primer edificio de oficinas construido para este propósito; mientras que muchas oficinas más pequeñas para la Royal Navy se consolidaron en Somerset House como el primer bloque de oficinas especialmente diseñado para esa función, a lo largo de la década de 1770

Figura 4. La Oficina del cuatro por ciento, obra del arquitecto John Soane, 1793

Figura 5. El primer “rascacielos” de Europa. Oriel Chambers, 1864.

Figura 6. El edificio Larkin alojaba a 1800 trabajadores y procesaba 5000 pedidos diarios

Figura 7. El rascacielos Friedrichstrass. Berlín, 1921

Figura 8. Planta del rascacielos Friedrichstrass

Figura 9. Johnson Wax Building, obra del arquitecto Frank Lloyd Wright. EEUU, 1939

Figura 10. Ejemplo de Action Office versión II en la década de 1960

Figura 11. Planta del Edificio Centraal Beheer. Holanda, 1958

Figura 12. Evolución histórica de los espacios de oficinas

Figura 13. De izquierda a derecha: Oficina Celular, Oficina de planta abierta o pradera, Oficina multi-espacio, Oficina-combi, Oficina flexible. (a) Despachos individuales (b) Zonas de trabajo (c) Zonas comunes. Fuente: elaboración propia

Figura 14. Imagen aérea del Distrito C de Telefónica. Distrito C supuso una inversión urbanística y empresarial de más de 500 millones de euros que contó con el diseño del arquitecto Rafael de la Hoz. Fuente: www.telefonica.com

Figura 15. Modelo de Excelencia EFQM. Fuente: Prof. Serio Vega Sánchez

Figure 16. Facility Management industry's future role conceptual model. Source: Self-made based in ISS World Services A/S, Copenhagen Institute for Future Studies (CIFS), 2013. ISS 2020 Vision: New Ways of Working - The Workplace of the Future, Soborg, Denmark: ISS World Services A/S

Figure 17. Outline of Intellectual Productivity Evaluation System. Source: Professor Ikaga Laboratory

Figure 18. Relationship between additional rent and economic effect. Tsubo is a Japanese unit of area (1 tsubo= 3.3 sqm). Source: Professor Ikaga Laboratory

Figure 19. Outside view of Kajima Corporation Technical Research Institute (KaTRI), Tokyo

Figure 20. Inside view of Kajima Corporation Technical Research Institute (KaTRI), Tokyo

Figure 21. Outside view of Shimizu Corporation Office Headquarters, Tokyo.

Source: www.shimz.co.jp

Figure 22. Inside view of Shimizu Corporation Office Headquarters, Tokyo.

Source: www.shimz.co.jp

Figure 23. Outside view of Nikken Sekkei Ltd. Office Headquarters, Tokyo

Figure 24. Inside view of Nikken Sekkei Ltd. Office Headquarters, Tokyo

Figure 25. Outside view of Nissan Office Headquarters, Yokohama. Source:

<http://www.nissan-global.com>

Figure 26. Inside view of Nissan Office Headquarters, Yokohama. Source:

<http://www.nissan-global.com>

Figure 27. Comparison of Satisfaction with Environmental Elements at Nissan headquarters. Source: Self-made based on Plan and Workplace Environmental Evaluation of a Low-carbon Office (Part6): Survey on Indoor Environment and Productivity and Evaluation of Reconstruction

Figure 28. Satisfaction with the environment. Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society"

Figure 29. Subjective evaluation on intellectual productivity (office area). Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society"

Figure 30. Comparison of assessment results between the old building and new building. Source: Self-made based on "The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society"

Figure 31. Distribution of energy consumption in office buildings in Australia.
Source: The Green Lease Handbook. Council of Australian Governments.
2012

Figure 32. Risk radar. Source: The Business Scenario for Green Building. World
Green Building Council. 2013

Figure 33. GPT Group Headquarters in Sydney. Interior view

Figure 34. GPT Group Headquarters in Sydney. Stairs

Figure 35. GPT Group Headquarters in Sydney. Workstations

Figure 36. IAG House Headquarters in Sydney. Facade

Figure 37. IAG House Headquarters in Sydney. Facade detail

Figure 38. IAG House Headquarters in Sydney. Access

Figure 39. 39 Hunter Street

Figure 40. 39 Hunter Street. Facade

Figure 41. 39 Hunter Street. Detail Facade

Figure 42. 39 Hunter Street. Communication core

Figure 43. 39 Hunter Street. Rooftop area

Figure 44. 39 Hunter Street. Rooftop area

Figure 45. 39 Hunter Street. Basement area

Figure 46. 39 Hunter Street. Lobby

Figure 47. 385 Bourke Street. Facade

Figure 48. 385 Bourke Street. Hall area

Figure 49. 385 Bourke Street. Building reception area

Figure 50. 385 Bourke Street. Workstations

Figure 51. 385 Bourke Street. Reception floor area

Figure 52. 385 Bourke Street. Restaurants area

Figure 53. Legacy House. Facade

Figure 54. Legacy House. Reception area

Figure 55. Ross House

Figure 56. Ross House. Facade

Figure 57. Ross House

Figure 58. Ross House. Stairs

Figure 59. 406 Collins Street. Facade

Figure 60. 406 Collins Street. Entrance

Figure 61. 406 Collins Street. Hall area

Figure 62. 131 Queen Street. Facade

Figure 63. 131 Queen Street. Entrance

Figura 64. Comunidad científica relacionada con métodos de cuantificación del impacto de entornos de trabajo en las variaciones de productividad y bienestar de las personas

CAPITULO III

Figura 1. Esquema de experiencia del usuario, base conceptual de la herramienta propuesta. Un experimento piloto simula la jornada diaria de una persona, como si de una película se tratara [1]. En esa película, analizamos fotograma por fotograma, compuesto por una capa de datos fisiológicos, capa psicológica, capa emocional y capa cultural [2]. Con un adecuado número de muestras, podemos combinar la información de las capas con resultados de tests relacionados con productividad y creatividad [3]. Si analizamos todas estas muestras, podemos identificar patrones y correlaciones [4]

Figura 2. Esquema de establecimiento de hipótesis en cada experimento piloto

Figura 3. Teoría de la diversidad cognitiva equiparando los espacios de oficinas con un zoológico. Autor: Nigel Risner

Figura 4. Esquema de mediciones que se realizan en cada experimento piloto, y que conforman la herramienta presentada

Figura 4. Interfaz de la tarea denominada “mecanografía”

Figura 5. Ejemplo de la tarea denominada “sumas”

Figura 6. Ejemplo de test de Stroop

Figura 7. Ejemplo de la tarea de trabajo simulado denominada “sudoku”

Figura 8. Esquema de tareas desarrolladas por el Cambridge Brain Institute

Figura 9. Ejemplo de Mapa mental

Figura 10. Método de Taxonomía del Pensamiento Creativo

Figura 11. Programación tipo de los experimentos piloto

Figura 12. Ejemplo de programación de dos días

Figura 13. Programación de la Fase 2 de Ejecución del Experimento Piloto

Figura 14. Flujograma de análisis de resultados de los experimentos piloto

CAPITULO IV. CASO DE ESTUDIO 1

Figure 1a. Interior of the experimental pilot location

Figure 1b. Exterior of the experimental pilot location

Figure 2. Pilot experiment schedule

Figure 3. Layout of the pilot experiment location

Figure 4a. T-Light Cube. Source: Taisei Corporation, Japan

Figure 4b. Photo of T-Light Cube. Mirrors system detail

Figure 5. Environment measurement station used during the pilot experiment

Figure 7. Physiological Measurement Schedule (Task Set 1, 2)

Figure 8. Satisfaction rate about greenery, among people exposed to the presence of greenery every day

Figure 9. The concentration of saliva amylase in each Scenario (Scenario 1: no daylight, no greenery; Scenario 2: no daylight, greenery; Scenario 3: Daylight and greenery)

Figure 10. Sympathetic activity while working LF/HF

Figure 11. Answer percentages to the question: " Did you feel that the thermal sensation was adequate?"

Figure 12. Drowsiness reporting ratio

Figure 13. Workload ratio

Figure 14. Results of the typing task in each Scenario

Figure 15. Results of the mind map task in each Scenario

CAPITULO IV. CASO DE ESTUDIO 2

Figure 1. Pilot experiment schedule.

Figure 2: Pilot experiment place layout.

Figure 3. Physiological Measurement Schedule (Task Set 1, 2).

Figure 4. The concentration of saliva amylase in each Scenario (Scenario 1: no greenery, no wood; Scenario 2: no greenery, wood; Scenario 3: greenery and wood).

Figure 5. Sympathetic activity while working in the morning LF/HF

Figure 6. Sleep Efficiency

Figure 7. Number of times awakened

Figure 8. Results of tasks in each Scenario 1 and Scenario 3

Figure 9. Results of concentration in creative tasks before work reported in each Scenario 1 and Scenario 3

CAPITULO IV. CASO DE ESTUDIO 3

Figure 1. Schedule

Figure 2. Daily schedule

Figure 3. Programming of physiological and psychological samples (it is repeated in the 3 work sessions)

Figure 4. Tests to evaluate the cognitive capacity for each skill

Figure 5. Flow diagram of the application of the ANOVA method in the design of the experiment

Figure 6. Analysis of normal distribution of productivity results. There are three values outside the normal distribution, two of which are extreme

Figure 7. Results of productivity improvement by type of office. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

Figure 8. Results of productivity improvement by activities carried out. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

Figure 9. Results of productivity improvement by type of office and activities carried out. Measure based on cognitive ability exercises (reasoning, memory and verbal skills)

Figure 10. Results of improvement of creativity by type of office: number of ideas generated. Measurement based on the taxonomy of creative thinking.

Figure 11. Results of improvement of creativity by type of office: improvement of generation of simple ideas (brainstorming). Measurement based on the taxonomy of creative thinking

Figure 12. Results of improvement of creativity by type of office: improvement of generation of complex ideas (innovation). Measurement based on the taxonomy of creative thinking

Figure 13. Results of improvement of creativity by type of office and by activities carried out. Measurement based on the taxonomy of creative thinking

Figure 14. Results of improvement of creativity by activities carried out. Measurement based on the taxonomy of creative thinking

Figure 15. Results of improvement of subjective motivation for activities carried out and types of space

Figure 16. Results of improvement of sleep quality score

Figure 17. Results of increased duration of deep sleep

Figure 18. Results of improvement of subjective well-being

Figure 19. Activity of the sympathetic nervous system in the morning. Comparison between the group that performs physical exercise and meditation with the control group

Figure 20. Activity of the sympathetic nervous system in the afternoon. Comparison between the group that performs physical exercise and meditation with the control group

CAPITULO V. CONCLUSIONES

Figura 1. Recopilación de resultados obtenidos en los tres casos de estudio en tareas no creativas

Figura 2. Recopilación de resultados obtenidos en los tres casos de estudio en tareas no creativas

Figura 3. Recopilación de resultados en los diversos casos de estudio que muestran una menor concentración de enzima amilasa en saliva en los grupos que usaron espacios de diseño biofílico

Figura 4. Recopilación de resultados en los diversos casos de estudio que muestran una mayor actividad del sistema nervioso autónomo en los grupos que usaron espacios de diseño biofílico

Figura 5. Mejores resultados de creatividad en el grupo que recibe formación a través de la gestión del cambio

Figura 6. Impacto en el resultado en motivación en el grupo que recibe formación a través de la gestión del cambio

Figura 7. Resultados de calidad del sueño comparando Caso 1 (grupo de control) y Caso 3 (grupo bajo la influencia de acabados de madera natural)

Figura 8. Lecciones aprendidas en las tres fases que componen la herramienta

INDICE DE TABLAS

CAPITULO II

Table I. Kajima Corporation Technical Research Institute Building Outline.

Table II Shimizu Headquarters building outline.

Table III Nikken Sekkei Headquarters building outline.

Table IV. Nissan Headquarters building outline.

Table V. Average Satisfaction Improvement at Kajima Institute. Source: Self-made based on **"Plan and Workplace Environmental Evaluation of a Low-carbon Office (Part6): Survey on Indoor Environment and Productivity and Evaluation of Reconstruction."**

Table VI. Average Work Efficiency Improvement at Kajima Institute. Source: [Miura, et al., 2013]

Table VII. Average Satisfaction Improvement at Kajima Institute. Source: Self-made based on **"Study on Urban High-Rise Office Building driving for ZEB. (Part 17). Effect evaluation of indoor Environments on Satisfaction and Productivity."**

Table VIII Item and level of intellectual productivity evaluation system. Source: Self-made based on **"The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."**

Table IX Intellectual productivity evaluation result and economic value (additional rent). Source: Self-made based on **"The 10th International Conference on EcoBalance (EcoBalance 2012)-Challenges and Solutions for Sustainable Society."**

Table X. Comparison of results between Scenario Studies.

Table XI. Expected business benefits of Green Building in Australia. Source: Green Building Council of Australia.

Table XII. Net present value of the operational cost and productivity and health benefits of LEED certified buildings. Source: The Business Scenario for Green Building. World Green Building Council. 2013.

Table XIII. Main data of Case Study 388 George Street, Sydney.

Table XIV. Goals achieved in Case Study 388 George Street, Sydney.

Table XV. Main data of Case Study 39 Hunter Street, Sydney.

Table XVI. Environmental initiatives in this project.

Table XVII. Main data of 385 Bourke Street, Melbourne.

Table XVIII. Architecture features of 385 Bourke Street, Melbourne.

Table XIX. Main achievements of 385 Bourke Street, Melbourne.

Table XX. Main data of Legacy House, Melbourne.

Table XXI. Main data of Ross House, Melbourne.

Table XXII. Architecture features of 385 Bourke Street, Melbourne Table XXIII. Main data of 406 Collins Street, Melbourne.

Table XXIV. Architecture features of 406 Collins Street, Melbourne.

Table XXV. Architecture outcomes of 406 Collins Street, Melbourne.

Table XXVI. Main data of 131 Queen Street, Melbourne.

Table XXVII. Architecture features of 131 Queen Street, Melbourne.

Table XXVIII. Architecture outcomes of 131 Queen Street, Melbourne.

CAPITULO III

Tabla I. Matriz de responsabilidades

Tabla II. Factores a considerar en la selección de personas participantes en los experimentos piloto

Tabla III. Caracterización de las variables utilizadas en los Casos de Estudio

Tabla IV. Configuración de escenarios con dos variables.

Tabla V. Mediciones fisiológicas

Tabla VI. Equipos de medición fisiológica

Tabla VII. Mediciones Psicológicas, emocionales y culturales

Tabla VIII. Mediciones de Productividad

Tabla IX. Mediciones de Creatividad

Tabla X. Mediciones ambientales

Tabla XI. Equipos de medición ambiental

CAPITULO IV. CASO DE ESTUDIO 1

Table I: Pilot experiment measurement items.

Table II: Pilot experiment setup combining the three Scenarios. Each Scenario combines greenery and daylight as variables.

Table III: Selected greenery

Table IV: Indoor Environment Measurement results during the pilot experiment ($\pm$ Standard Deviation).

Table V: Correlation analysis result of satisfaction about greenery degree and psychological quantity.

Table VI: Correlation analysis result of the presence of daylight and psychological quantity

CAPITULO IV. CASO DE ESTUDIO 2

Table I: Pilot experiment measurement items.

Table II. Pilot experimental schedule and Scenarios.

Table III: Selected greenery.

Table IV. Two different rooms.

Table V. Environmental equipment and measurement method.

Table VI. Environmental results.

Table VI. Physiological equipment and measurement method.

Table VII: Correlation analysis result of success rate in tasks and physiological and psychological quantity in Scenario 3

CAPITULO IV. CASO DE ESTUDIO 3

Table I. Measurements carried out.

Table II. Distribution of the four groups. All the groups follow the same path of Ugly, Optimum and Beautiful office.

Table III: Pilot Experiment configuration combining twelve Scenarios. Each Scenario combines as variables: type of space, training through change management, physical exercise and meditation.

Table IV: Results of the internal environmental measurement during the pilot experiment ($\pm$ Standard Deviation).

Table V. Dependent and independent variables used in the ANOVA method.

Table VI. Saphiro-Wilk test results.

Table VII. ANOVA Analysis

Table VIII. Levene Test

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