DIGITAL WINDOW

AN OPENING BETWEEN DOMESTIC SPATIALITY AND DIGITAL INFORMATION

volume **1**

Alex Nogueira Rezende

Orientador: Doutor Luís António dos Santos Romão

DOUTORAMENTO EM ARQUITETURA
TEORIA E PRÁTICA DO PROJETO (TPP)
Tese especialmente elaborada para a obtenção do grau de doutor
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FACULDADE DE ARQUITETURA
LISBON SCHOOL OF ARCHITECTURE
UNIVERSIDADE DE LISBOA

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Digital Window

An opening between Domestic Spatiality and Digital Information

VOLUME 1

Alex Nogueira Rezende

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“No sólo he imaginado esos juegos; también he meditado sobre la casa. Todas las partes de la casa están muchas veces, cualquier lugar es otro lugar. No hay un aljibe, un patio, un abrevadero, un pesebre; son catorce [son infinitos] los pesebres, abrevaderos, patios, aljibes. La casa es del tamaño del mundo; mejor dicho, es el mundo.”

Jorge Luis Borges[1]

[1] Borges, J. L. (2007). La Casa de Asterión [The House of Asterion]. In *El Aleph*, Emecé, Buenos Aires. (Original work published 1949)

Abstract

Starting from the house as the general space of study, this research is dedicated to the proposition of a possible interweaving between architecture and computing. Its main objective is to develop a human-based architectural system that seeks in the relationship involving domestic spatiality and digital information to enhance the domestic experience of the inhabitant. The research is justified by the perception that architectural work has incipiently explored advances in information technology; and because there is a mismatch regarding the demands arising from contemporary ways of living and the predominant architectural production. The panorama of research performance is rooted in demands linked to population aging and the consequent concept of aging in place. The methodological structure is divided into five phases: (a) Explanatory, relating the themes of domesticity, cybernetics, and artificial intelligence through a literature review; (b) Conceptual Proposition, also resorts to a bibliographical review and analysis of related works to establish the concept of digital window, which starts by analyzing the blurring of dualities in contemporary times and its implications to the perception about the concepts of prosthesis and materiality; (c) Approximation, corresponds to data collection through the consultation of official documents, application of surveys, and unsystematic observation capable of verifying population aging in Lisbon, highlighting nuances related to this phenomenon, and establishing a context to develop the Digital Window System; (d) Development, presents the elaboration of the high fidelity prototype of the Digital Window System apparatus, where hardware and software form a manifestation of the digital window concept; (e) Evaluation, consists of carrying out a test based on the use of the apparatus by older adults to evaluate the usability besides other aspects of the system, aiming at its validation and future improvements. The evaluation obtained, generally positive, shows that both the system and the way it was developed are significant contributions from the research.

Keywords: Domesticity; Cybernetics; Artificial intelligence; Aging in place; Digital Window System.

Resumo

Partindo da casa como o espaço geral de estudo, esta pesquisa se dedica a proposição de um entrelaçamento possível entre arquitetura e computação. Seu objetivo principal é desenvolver um sistema arquitetônico baseado no humano que busque no relacionamento da espacialidade doméstica e da informação digital meios de potencializar a experiência doméstica do habitante. A pesquisa se justifica pela percepção de que o fazer arquitetônico tem explorado incipientemente os avanços das tecnologias da informação; e por haver um descompasso entre as demandas oriundas de modos de viver na contemporaneidade e a produção arquitetônica predominante. O panorama de atuação da pesquisa advém de demandas relacionadas ao envelhecimento populacional, e do decorrente conceito “aging in place”. *A estrutura metodológica está dividida em cinco fases: (a) Explicativa, relaciona os temas domesticidade, cibernética e inteligência artificial por meio da revisão de literatura; (b) Proposição Conceitual, também recorre à revisão bibliográfica e análise de trabalhos correlatos para estabelecer o conceito de janela digital, o qual parte da análise do enfraquecimento de dualidades na contemporaneidade e suas consequências na percepção dos conceito de prótese e materialidade; (c) Aproximação, corresponde ao levantamento de dados através da consulta à documentos oficiais, aplicação de inquéritos, e observação assistemática capazes de verificar o envelhecimento populacional em Lisboa, evidenciar nuances decorrentes deste fenômeno, e estabelecer um contexto de desenvolvimento do* Digital Window System; *(d) Desenvolvimento, apresenta a elaboração do protótipo de alta fidelidade do aparato do* Digital Window System, *onde hardware e software formam uma manifestação do conceito de janela digital; (e) Avaliação, consiste na realização do teste baseado na utilização do aparato por adultos mais velhos para avaliar a usabilidade e outros aspectos do sistema, objetivando sua validação e melhorias futuras. A avaliação obtida, no geral positiva, mostra que o sistema e seu modo de desenvolvimento são significativos contributos da pesquisa.*

Palavras-chave*: Domesticidade; Cibernética; Inteligência artificial*; Aging in place; Digital Window System.

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Acronyms and Abbreviations

AI	*Artificial Intelligence*
AiP	*Aging in place*
DWS	*Digital Window System*
INE	*Instituto Nacional de Estatística* [*Statistics Portugal*]
FA.Ulisboa	*Faculdade de Arquitetura da Universidade de Lisboa* [*Lisbon School of Architecture*]
DTL	*Domesticity and Technology in Lisbon (survey)*
ML	*Machine Learning*
US	*United States of America*
MIT	*Massachusetts Institute of Technology*
WHO	*World Health Organization*
GPS	*Global Positioning System*
SAKI	*Self-Adaptive Keyboard Instructor*
AA	*Architectural Association School of Architecture*
AD	*Architectural Design*
MV	*Machine Vision*
B.C.E.	*Before the Common Era*
NLP	*Natural Language Processing*
Lisp	*List Processing*
IBM	*International Business Machines Corporation*
CBR	*Case-Based Reasoning*
ITS	*Intelligent Tutoring Systems*
sci-fi	*Science Fiction*
BE	*Belgium*
MoMA	*The Museum of Modern Art*
H.O.F.	*House of the Future (by Smithsons)*
FPC	*Fundação Portuguesa das Comunicações*
IFTTT	*If This Then That*
IUTICF– 2020	*Inquérito à Utilização de Tecnologias da Informação e da Comunicação pelas Famílias – 2020* [*Survey on the Use of Information and Communication Technologies by Families – 2020*]
AML	*Área Metropolitana de Lisboa* [*Lisbon Metropolitan Area*]
ISCSP	*Instituto Superior de Ciências Sociais e Políticas*
UTIL	*Universidade da Terceira Idade do Lumiar*

SCML	*Santa Casa da Misericórdia de Lisboa*
UISTC	*Unidade de Inovação Social e Transferência de Conhecimento* [*Social Innovation and Knowledge Transfer Unit*]
UDIP	*Unidades de Desenvolvimento e Intervenção de Proximidade* [*Proximity Development and Intervention Units*]
ZDB	*Galeria Zé dos Bois* [*Zé dos Bois Gallery*]
DWA	*Digital Window App*
AR	*Augmented Reality*
VR	*Virtual Reality*
GUI	*Graphical User Interface*
CAD	*Computer-Aided Design*
HMM	*Hidden Markov Model*
CMOS	*Complementary Metal-Oxide Semiconductor*
CCD	*Charge-Coupled Device*
RGB	*Red/Green/Blue*
DXF	*Drawing Exchange Format*
STL	*Standard Triangle Language*
LPR	*Laboratório de Prototipagem Rápida*
CNC	*Computer Numerical Control*
FDM	*Fused Deposition Modeling*
USB	*Universal Serial Bus*
V	*Volts*
A	*Ampere*
kg.cm	*kilogram per centimeter*
VPL	*Visual Programming Language*
MIT CSAIL	*MIT Computer Science and Artificial Intelligence Laboratory*
PIC	*Personal Image Classifier*
SIC	*Sociedade Independente de Comunicação* (television channel)
TVI	*Televisão Independente* (television channel)
CDCBL	*Centro de Desenvolvimento Comunitário do Bairro dos Lóios* [*Bairro dos Lóios Community Development Center*]

Introduction

Introduction

This section presents the general structure of the research, its main concerns, motivations, goals, and methodologies applied. Thus, this introductory text consists, respectively, of research background and problems; research goals (main and secondary); research questions (main and secondary); hypothesis; research methodology (organized into five phases); significance; academic developments; presentation of the thesis structure; and the list of bibliographic references of the introduction.

a. Research Background and Problems

This research finds in the house its general corpus of work within the scope of architecture. Such choice is justified because the house has a primary function of sheltering and formatting dwelling. Therefore, the house is the space par excellence for developing domesticity. It is still possible to justify this interest in other ways, for the house can be understood as a kind of barometer of contemporaneity, as stated by Gonçalo Furtado and Inês Moreira (2001). These authors, additionally, claim that the domestic sector is predominant in the constitution of cities and, thus, becomes the most demanded architectural program. Also noteworthy is the fact that the house is the space with which people usually develop a greater relationship of intimacy and permanence, in addition to being an essential social component (p. 96).

The interest registered herein about contemporary dwelling rests on a possible mismatch verified between architectural production and the diversified demands of society. Standards that were once massive continue to serve as the chief parameter for new housing, even when they do not correspond to the real needs of a significant population cohort. While in the field of urbanism, for example, part of the modern assumptions has already been overcome, the same is not verified in the contemporary interior design of the house (Marques Pereira, 2004, p. 91).

Furthermore, it is worth noting society's diverse demands and that they continuously change, often posing new challenges to architecture. Whether in the new and multiple family configurations, in the increase of individual dwelling, other ways of relating home and work, or in the significant aging of the population, among other issues that constantly flourish in contemporary times (Fernández Lorenzo, 2012).

Parallel to the mismatch previously mentioned as regards architectural production and contemporary demands, other reflections inquire the current nature of architectural work in relation to the impactful technological transformations that have occurred throughout recent decades, especially those arising from the evolution of computing. For example, Architect Ted Krueger (2006) believes that architecture has neglected the possibilities offered by new technologies. The author points out that, even if these possibilities are indifferent to most architects, new technologies still prove to be an important field for exploring relationships involving space and its operability (p. 101).

It is necessary to consider that in contemporary times a series of dichotomies have had their limits blurred due, among other factors, to the intensification of mechanization verified predominantly from the twentieth century on, which also occurs to the domestic space (Vidler, 1992); and of which the advent of computing is a considerable part. This phenomenon has had direct implications for some concepts relevant to architecture, such as prosthesis (Wigley, 2010) and materiality (Picon, 2003), for example.

Accordingly, the prosthetic relationship between body and machine is spatially established within a scenario where the technological culture alters the experience of materiality. In this context, this research starts from the premise that "the urgent task architecture ought to assume, therefore, is that of defining and imagining an environment not just for 'natural' bodies, but for bodies projected outside themselves, absent and ecstatic, by means of their technologically extended senses" (Teyssot, 2005, p. 81).

The blurring of dualities also led to questioning the role of an omnipresent architectural element, the window. During modern architecture, this element had its role expanded and modified, especially by the consolidation of mass media (Colomina, 1994). In this context, the window ceases to have the simple function of illuminating and ventilating; and becomes the "picture window." In this process, the window increasingly assumes the role of a screen (p. 6).

Architect, Historian, and Theorist Anne Friedberg (1952–2009) understands that the metaphor of the window as a screen, which emerged with Leon Battista Alberti (1404–1472) during the Renaissance, remains valid in contemporary media, either on the screen of the cinema, television, computer or cell phone (Friedberg, 2006). Based on the metaphor of the window as a screen, this research develops the digital window concept (Chapter 2), a metaphorical architectural element based on visualizing digital information through built space.

Therefore, this research assumes that exploring different perspectives on architecture amid various transformations and expanding concepts is possible. In certain scenarios, architecture can be understood as a system designed to meet specific demands within a specific context and in which the information exchange process is continuous. In this systemic approach to architecture, areas such as cybernetics provide a theoretical framework capable of guiding alternative means of architectural production (Pask, 1969).

Understanding architecture as a system and the establishment of digital information (from advances in computing and massification of the internet) has generated a set of experimental architectural projects exploring this tangency (Bullivant, 2005a; Carpo, 2013). This way of producing architecture, among others, can be framed within what Architect, Historian, and Theorist Beatriz Colomina (Colomina, 2016) classifies as radical or disruptive proposals.

A systemic approach to architecture can seek support in computing and take advantage of its mathematical logic. Within this field, it is possible to envisage emerging techniques of artificial intelligence (AI). AI is a branch of computer science that has presented a growing number of applications and functionalities and is already omnipresent in several sectors of contemporary society (Oliveira, 2017, p. 81). AI can be used as a facilitating tool for interaction between humans and machines, space and machines, and, consequently, between humans and space. This is an essential premise for this research.

In this context, the research presents a way of thinking about architecture based on contemporary demands and pursues computing and AI support to enhance the process. Within the plurality of ways of living, as previously discussed, the research explores issues related to the significant population aging observed in many countries. A combination of different factors causes such a phenomenon: the increase in life expectancy, the decrease in fertility rates, and the aging of the “Baby Boom” of World War II stand out (Coughlin, 2019, p. 33), among others. This fact generates scenarios with considerable implications for architecture and urbanism.

Working with issues linked to population aging are even more justified in the context of Lisbon, the geographical area of this research. Recent data indicate that practically a quarter of the Portuguese capital’s population is aged 65 or over (INE, 2021b). It is important to point out that said population slice faces a series of challenges inherent to the natural aging process. Among these challenges, some issues do not relate to architecture; however, others can be supplied or mitigated through architectural artifices.

Many works that explore a similar premise, not infrequently, address the mobility issue. Despite the relevance of such dimension, it is not the focus herein. Instead, this work is based on the concept of *aging in place*[2] (AiP), which advocates the search for an expansion of conditions so that older adults can remain in their own homes for as long as possible, avoiding institutionalization and questing to preserve the relationships already established throughout life with the place and its community (Joint Center for Housing Studies of Harvard University, 2016, p. 69).

Intending to build a broader—and less stereotyped—perception of the target audience (older adults in Lisbon), it was necessary to add tools for directly collecting information to the methodological repertoire of this

[2] Since this work has been written in U.S. English, the spelling used herein is “Aging in place;” however, the term can also be found in British orthography as “Ageing in place.”

research (“e. Research Methodology”). This process sought to investigate habits, domestic relationships, and verify how this portion of the population related to some electronic devices in their domestic context. From the results of this research stage, it was possible to understand and delimit which demands would be relevant in developing the proposed system, the Digital Window System (DWS).

Therefore, this research takes an unusual path to propose an architectural system based on the relationship between domestic spatiality and the visualization and manipulation of digital information, aiming to meet specific contemporary demands and enhance the inhabitants’ domestic experience. Such proposition develops from a set of factors and references composed by the legacy of pioneering works with comparable ambitions that were based on cybernetic theory; for the digital window concept and works related to this concept; by advances in computing; and for some habits and needs of older adults observed and registered during this work. Next, the other topics presented in this introduction describe the research development and its main structuring points.

b. Research Goals

Main goal

Develop an architectural system, based on the relationship between domestic spatiality and digital information, capable of enhancing the inhabitant’s domestic experience, which is the central point of this relationship.

Secondary Goals

Except for this introductory text and the conclusion, all other chapters are directly related to the secondary goals of this research, namely:

1) *Domesticity, Cybernetics, and Artificial Intelligence*: to establish a historical, theoretical, and critical record of the main concepts related to the topics covered. To highlight the architectural implications related to the themes worked. Third, to relate domesticity with ways of living, presenting developments related to population aging

and the concept of AiP. Finally, to introduce cybernetics as a systemic approach to information that can encompass architecture and allow relating it to artificial intelligence.

2) *Digital Window Framework*: to propose the digital window concept, a metaphor established from the interweaving of structuring concepts discussed in contemporary architecture, such as materiality, prosthesis, and the blurring of dualities. To present related works that exemplify the concept proposed.

3) *Lisbon Context*: to create a database—among data already available and others raised during this research—qualified for contextualizing the issue of population aging in Lisbon (said data set aims to serve as a premise for the following developments).

4) *Digital Window System*: to develop a system capable of representing a possible manifestation of the digital window concept. To be compatible with the specific demands of older adults, previously contextualized. To present the elaboration of the physical (hardware) and abstract (software) elements that make up the apparatus developed.

5) *Evaluation of Digital Window System*: to test the Digital Window System apparatus. Based on the test, to evaluate the proposed system regarding its usability, performance, preferences, and other dimensions. Mapping possibilities for improvement.

c. Research Questions

Main Research Question

a) Can the development of a human-centered architectural system, based on the relationship involving domestic spatiality with the visualization and manipulation of digital information, benefit the inhabitant?

Secondary Research Questions

b) What would be the appropriate methodology to achieve the goals established? Could such methodology be useful for other studies of a similar nature?

c) Are the theoretical structure and the conceptual interweaving proposed coherent with the system developed?

d) Is the developed system able to support the inhabitant's specific demands (in this case, older adults)? What types of demands can be addressed?

d. Hypothesis

Relating domestic spatiality with digital information can allow the creation of new architectural systems beneficial to the inhabitants.

e. Research Methodology

The methodological proposal structuring the development of this research is divided into five phases. The first one corresponds to the Explanatory research. The second phase consists of the Conceptual Proposition. The third one is responsible for Contextualization. The fourth phase is characterized as Development. The fifth and final phase consists of the Evaluation. However, it is relevant to emphasize that these phases are not isolated and are combined and feedbacked in different ways. Formally, these five phases reflect the chapter division of the research. The five phases can be summarized as follows:

a) *Explanatory Phase*: it consists of the literature review, which is formed by four main stages: information collection, information selection, information analysis, and synthesis (Wang & Groat, 2013, pp. 142–143). State of the art was developed through the bibliographical research undertaken in this phase. The topics studied comprise the entirety of Chapter 1 and a significant part of Chapter 2 and are reflected in the development of all other chapters.

b) *Conceptual Proposition Phase*: this phase encompasses a set of methodological tools that allow structuring the digital window concept (proposed in Chapter 2). The literature review, already mentioned, and other tools that help identify this concept in a small group of related works (Princeton, 2019). This corpus was split into two sections: architectural narratives and cinematographic narratives, both presented in Chapter 2. To address this diversity of information, in addition to the literature review, it was necessary to employ focused interviews (Marconi & Lakatos, 1985/2002, p. 94), unsystematic observation (pp. 89–90), and in loco visits (p. 63).

c) *Contextualization Phase*: focuses primarily on two complementary methodological techniques, namely documentary research and the application of surveys. Additionally, unsystematic observation was an important methodological resource for recording data of a non-quantitative nature. The sum of these instruments was utilized to comprehend the occurrence of the phenomenon regarding population aging in the context of Lisbon. Jointly using the analysis of official documents (Marconi & Lakatos, 1985/2002, p. 65) from Instituto Nacional de Estatística (INE; Statistics Portugal) and extensive direct observation techniques (p. 98), as well as unsystematic observation (pp. 89–90), allows to understand and record nuances resulting from this phenomenon. Accordingly, the application of questionnaires (p. 98) and forms (p. 112) prove to be valuable tools in the process of contextualizing the phenomenon of population aging concerning the theoretical premises structured in the research previous stages and, upon it, guide the developments in the following steps.

d) *Development Phase*: comprises the elaboration process of the Digital Window System, based on the correlation of the theoretical framework explored within the first two chapters with the data collected in Chapter 3. Such development is based methodologically on creating a high-quality prototype (Saenz & Valencia, 2012, p. 482). The prototype encompasses its hardware and software developments, becoming a fundamental piece during the last phase of the research, its evaluation.

e) *Evaluation Phase*: its main objective is to validate the research hypothesis. The planned evaluation is carried out by a set of methodological tools that make up the test “User Evaluation of DWS.” The principal of these tools was the application of the post-test form, which was designed to evaluate multiple dimensions of the developed system, among them the system usability (Barnum, 2010, p. 176). In addition, to help with this task, systematic observation (Marconi & Lakatos, 1985/2002, p. 90) and the think-aloud protocol (Olmsted-Hawala et al., 2010, p. 2381) were also included, both concomitant to the test.

f. Significance

The principal contribution of this research is the development of an architectural system to support the inhabitant’s domestic experience. The proposed system starts from the relationship between domestic spatiality and digital information, having the human as its central figure. Accordingly, certain types of contemporary demands can be incorporated into the system, as presented in the Digital Window System.

The contextualization stage allowed to understand issues related to population aging and verify particularities of this process in Lisbon. Then, the system was developed to respond to some of the sensitive points mapped. In this way, the proposed system is based on domestic spatiality with the visualization and manipulation of digital information to help the inhabitant, facilitating the possibility of digitally including older adults, their entertainment, and communication with family and friends, among others.

These applications can potentially facilitate and improve the conditions for older adults to stay longer in their homes (aging in place concept). However, in other studies, this same investigative scope may be applied (or adapted) to map other contemporary demands, being a possible object of work for developing new alternative architectural systems.

All methodological resources used in carrying out this research proved to be effective and complementary. Therefore, the theoretical framework developed, the related works gathered, and the context structured by the data collected were basal for developing the Digital Window System. Hence, the methods used for testing and consequent evaluation of the system developed also deserve a highlight. Furthermore, this set of methods can be considered significant for being replicable in other works pursuing similar goals. Consequently, this methodological framework has the potential to support other unusual design approaches, such as the one developed in this research.

The evaluation from the “User Evaluation of DWS” test, in general, brought positive results. According to the data from the Digital Window System evaluation—about its usability—it is possible to regard the system as efficient, effective, and with the participants feeling involved. On the other hand, the data were less positive regarding ease of use, showing that the system can be even more straightforward. Furthermore, the errors that occurred during the test were not frequent; but they highlighted the system weak points (linked predominantly to the artificial intelligence device responsible for speech recognition). These data are relevant because they demonstrate the system qualities and problems besides attesting to the usability assessment as an adequate method to evaluate the system. Thus, the usability assessment (Barnum, 2010) can serve as a reference for other developments of a similar nature.

Other points highlighted in the evaluation process showed that, generally, participants considered that the system could improve the quality of time spent at home. The data obtained indicated that participants understood the system as a facilitator in using the internet at home and communicating with family, friends, and institutions. According to the participants, the system dynamic aspect was considered relevant for its use. The post-test form also raised other user preferences. This set of information, in addition to validating the working hypothesis, is important for helping to map the gaps in the system and, consequently, indicate possibilities for further improvements.

Both the evaluative data and the analysis of the development process of the proposed architectural system are significant because they represent an alternative approach to the mismatch between architectural production and the contemporary demands mentioned in “a. Research Background and Problems.” In addition to the practical implications of what was developed, the results of this research show that the approximation between architecture and computation—mediated by cybernetic theory—is a possible and fruitful design path, and that, therefore, deserves to be encouraged. Establishing the digital window concept, essential for the developments presented herein, is also a contribution that goes beyond the manifestation developed through the Digital Window System and may, in other studies, gain new interpretations or applications.

g. Academic Developments

As of the second half of 2018, having been admitted to the Ph.D. in architecture at the Faculdade de Arquitetura da Universidade de Lisboa (FA.Ulisboa), much knowledge has been either acquired or improved throughout the program. Such knowledge, worked together with the most diverse professors of the doctoral program and, in particular, with the research supervisor, forming the basis of this thesis. In this academic path, the various courses attended have, directly or indirectly, contributed to the development of this research.

Hence, this section briefly records part of these contributions, listing the academic articles developed in some of these disciplines or specifically for related events (presented in chronological order of publication). Finally, a highlighted on how these articles were important for the delimitation of the theme of this research and its development.

The article “Paper as a Flexible Alternative Applied to the Dom-Ino System: From Le Corbusier to Shigeru Ban” (“Appendix A”) was developed within the scope of the course “Plasticidade do Papel no Processo Criativo nas Artes, Arquitetura e no Design," conducted by Professor Mário Say Ming Kong (co-author of the article), between 2018 and 2019. Broadly, the article questions aspects regarding flexibility in the contemporary domestic space, with the proposal of modular paper panels a feasible alternative to help in the search for more flexible spaces (using experiences ranging from Le Corbusier to Shigeru Ban). This article contributed to the delimitation of the domestic space as the area of work in this research. The article (Nogueira & Kong, 2020, pp. 125–129) was presented at the *5TH INTERNATIONAL AND MULTIDISCIPLINARY CONGRESS PHI 2019* (Paris, 2019) and was published in the book *PHI: Intelligence, Creativity, and Fantasy* (Kong & Monteiro, 2020).

The article "Shape Grammars as a Method to Introduce Computational Thinking in Design" ("Appendix B") was developed within the scope of the course "Gramáticas da Forma," conducted by Professor Luís António dos Santos Romão (co-author of the article, and supervisor of this research), between 2018 and 2019. The article briefly explores a methodological design process based on shape grammars and computational thinking. The study is based on a selection of works by two artists (Athos Bulcão and Maria Keil) that support new creations via a repertoire of shapes incorporated into the algorithm developed. Through this article, computing came to be understood as a possible way of architectural conception (in addition to a graphical representation tool), which, otherwise, is explored in this thesis. The article (Nogueira & Romão, 2020, pp. 693–702) was presented at the conference *Anthropologic – Architecture and Fabrication in the cognitive age* (Berlin, 2020) and was published in the book *Proceedings of the 38th International Online Conference on Education and Research in Computer Aided Architectural Design in Europe* (Werner & Koering, 2020).

The article "Towards a Digital Window" ("Appendix C") was developed within the scope of the course "Teoria e História da Computação em Arquitetura," conducted by Professors Jorge Luís Firmino Nunes and Luís António dos Santos Romão (both co-authors of the article), in 2020. The article is based on the development of visual experiences seeking to simulate a window through the visualization of digital information. These simulations are deeply influenced by the book *The Virtual Window: From Alberti to Microsoft* (Friedberg, 2006). Regarding to the development of this research, it can be understood as a synthesis of initial inspirations and theoretical support that were better developed as the research advanced. Among these inspirations, the article addressed the *janelar* phenomenon observed in Lisbon and linked it to older adults (Chapter 3). Regarding the theoretical basis, this article lists a group of authors who, in different ways, deal with the impacts on architecture caused by advances in computing (and the popularization of the internet) and the establishment of the metaphor between the conventional architectural window and the digital one (Chapter 2). The article (Nogueira et al., 2020, pp. 15–26) was published in the Journal *Spool* (TU Delft), in volume number seven, entitled *Actuated and Performative Architecture: Emerging Forms of Human-Machine Interaction* (Pillan et al., 2020).

The article "Porto Faculty of Architecture's Project Evolution Under Other Perspectives" ("Appendix D") was developed within the scope of the course "Cartografias do Olhar," offered in 2019, by Professors Ana Cristina dos Santos Guerreiro, José Vítor Correia, Luís António dos Santos Romão, and Manuel Jorge Rodrigues Couceiro da Costa (with Professor José Vítor Correia co-authoring the article). In short, the article uses a variety of models from unusual perspectives to verify aspects of the evolutionary hypothesis regarding the architectural project of the Faculty of Architecture of Porto, designed by Architect Álvaro Siza Vieira. Even if the universe of the article is, in general, different from the knowledge explored herein, the matter of cartographic projections and the use of different models of perspectives helped to glimpse spatial possibilities about the projections (projection of light) that came to become important to the conception of the Digital Window System (Chapter 4). The article (Nogueira & Correia, 2021, pp. 209–215) was published as a chapter in the book *PHI: Tradition and Innovation* (Monteiro & Kong, 2021).

The article "Domesticity and Artificial Intelligence: Toward New Design Approaches" ("Appendix E") was developed in 2021, in co-authorship with the supervisor Professor Luís António dos Santos Romão. The article was submitted to the *10º PROJETAR 21* (Lisbon). In the article, AI is understood as a set of mathematical models that can be used in the architectural design process to facilitate the relationship involving the inhabitant, the domestic space, and digital information. It shares some relevant assumptions in the context of this research and explores several related themes. Among them are domesticity, cybernetics, and the very concept of AI stand out. Both in the article and in this research, AI is understood as a resource capable of facilitating the process of interaction between the inhabitant and digital information. The article (Nogueira & Romão, 2021, pp. 1110–1119) was published in the third volume of the book resulting from the event *ARQUITETURA, CIDADE E PAISAGEM: PROJETAR EM CONTEXTO DE CRISE Novos Desafios para o Ensino, a Pesquisa e a Prática da Arquitetura* (Pinto et al., 2021).

The article "The Future of the Past: Housing in Blade Runner" ("Appendix F") was developed within the scope of the course "Arquitetura da Habitação II," offered in 2019, by Professors Hugo Lopes Farias and José António Jacob Martins Cabido (Professor Hugo Lopes Farias is co-author of the article). The article analyzes some domestic relations in the dwellings of the protagonist androids of *Blade Runner* (Scott, 1982) and *Blade Runner 2049* (Villeneuve, 2017). Within this context, transformations and permanence in the relationship between domesticity and technology were verified in the 35-year interval (and 30 years in the fictional narrative) that separate the release of the two science fiction movies. The article was significant to this research for tracing relationships between domesticity and technology (still in a broad sense) and understanding cinema as a relevant field of architectural analysis. Such an understanding reverberated in the development of the section "2.4.2 *Cinematographic Narratives*." The article (Nogueira & Farias, in press) was presented at the *Space International Conference 2021* (London) and has been accepted for publication in the book resulting from the event, still in the printing process (SPACE, in press).

The article "room_ID: An Architectonic Image Classifier Tool Correlating Machine Learning and the Domestic Space" ("Appendix G") was developed between 2021 and 2022, in co-authorship with the supervisor

Professor Luís António dos Santos Romão. The article portrays the development of an AI mobile application that recognizes the main domestic spatialities through image recognition. The development of this application was valuable for many of the outcomes that followed and are recorded in this thesis. This is noticeable, firstly, in consolidating a theoretical basis for AI and improving techniques and practices related to the development of computational tools (Chapter 4). The article (Nogueira & Romão, 2022) has been recently submitted for publication.

Through these articles, it is possible to perceive part of the evolutionary paths of this research. Moreover, they allowed the development, structuring, and dissemination—via participation in scientific events and specialized publications—of a significant portion relating the subjects addressed during the Doctoral Program in Architecture at FA.Ulisboa. It should also be noted that the articles are available in their entirety at the initial part of Volume 2 of this thesis.

h. Thesis Structure

The thesis is structured into five chapters, divided into two parts. In addition to its main body, the thesis also comprises this introductory text, its conclusion, and pre-textual as well as post-textual elements (bibliographic references, annexes, and appendices). For reasons regarding organization and amount of information, 22 appendices were grouped in a second volume (and four annexes), while the sum of all the other parts mentioned forms the first volume. In Volume 2, information of a diverse nature is compiled, produced in the course of this research (and which supports specific parts of Volume 1), additionally, a smaller final part is made up of the annexes included. The main sections of Volume 1 are:

a. **Introduction**: this text presents the research theme and its principal implications, contexts, and boundaries. To this end, general dimensions of the research are introduced, such as research background and problems, goals (main and secondary ones), research questions, hypothesis, methodology, significance, and related academic developments.

b. **Part 1 - Toward a Digital Window**:

1) *Domesticity, Cybernetics, and Artificial Intelligence*: in this first chapter, the conceptualization, collection, and relationship involving the central themes of this investigation are developed. In this way, domesticity, cybernetics, and artificial intelligence are analyzed through a historical, theoretical-conceptual, and critical-analytical approach, having architecture as a background, seeking to relate these unique themes. The state of the art of these topics is developed using literature review as its methodological instrument.

2) *Digital Window Framework*: upon starting from the theoretical framework outlined in the previous chapter, it was possible to explore more specific concepts and phenomena, such as the evolution of prosthesis and materiality, besides the blurring of dichotomies observed in contemporaneity. Based on this theoretical structure, the digital window concept is stated, serving as basis for the developments proposed in the second part of the research. Also, in this second chapter, related works are presented that, to some extent, incorporate or present similarities with the digital window concept. The leading methodological resource of this chapter continues to be the bibliographic review; however other methods are starting to be explored in a supporting way, such as in loco visits, interviews, and unsystematic observation.

c. **Part 2 - Building a Digital Window**:

3) *Lisbon Context*: based on the premise established in Chapter 1, that population aging is a phenomenon impacting contemporary ways of living, with architectural implications, it becomes necessary to contextualize the phenomenon in Lisbon. Therefore, in addition to data made available by the public administration, referring to the verification of the phenomenon regarding population

aging in Lisbon, data were also collected that aim to map domestic habits and how this section of the population relates to certain information technologies. Thus, in this third chapter, the data collection undertaken in the "Domesticity and Technology in Lisbon" (DTL) survey is structured. Next, the results are analyzed, providing a context for developing and applying the digital window concept addressed in the previous chapter. The primary methodological resources employed were the consultation of official data, the availability of questionnaires (online), the application of forms (face-to-face) with the target audience, and unsystematic observation.

4) *Digital Window System*: this fourth chapter presents the development of a system capable of representing some possible manifestation of the digital window concept. The initial part of the chapter shows how the contexts analyzed in the previous ones, especially in Chapter 3, were taken into account in elaborating the system. Next, machine learning (ML) techniques (a relevant branch of AI) were deepened, intending to base resources used in the system. Finally, the development of the physical apparatus (hardware) and its corresponding application (software)—set that forms the Digital Window System—were detailed.

5) *Evaluation of Digital Window System*: this fifth chapter covers the performance of the test to evaluate the Digital Window System. Initially, the assumptions and objectives of the test are evidenced. Next, the test itself and the profile of participants are described. Then, the methodological tools employed are presented: systematic observation, think-aloud protocol, and application of a post-test form. Finally, the results collected are reported and analyzed, allowing to generally evaluate the system usability, as well as the verification of users' preferences and aspects related to the digital window concept and notes for possible improvements. This evaluative stage allows for verifying the validation of the research hypothesis.

d. **Conclusion**: this section presents a general synthesis of the research. This text attempts to show how the goals achieved relate to the hypothesis and the primary research questions. Furthermore, this section highlights the principal contributions achieved, recommendations, and notes for future works.

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[part 1]

Toward a Digital Window

Domesticity, Cybernetics, and Artificial Intelligence

[chapter]

1

Domesticity, Cybernetics, and Artificial Intelligence

This chapter presents the core theoretical references regarding domesticity, cybernetics, and artificial intelligence. The structure of the chapter seeks to provide a historical, conceptual, and critical approach to these topics for highlighting and establishing some crucial relationships in this research. The primary methodological path employed is the literature review, which structures the theoretical framework and leads to understanding the key issues. Such issues, sometimes more general, sometimes more specific, contextualize and ground the development of the digital window concept.

1.1 Introduction

Through a theoretical survey about the concepts regarding domesticity, cybernetics, and artificial intelligence, this chapter quests to delimit and contextualize the research problem. This task allows the research to have an overview of these topics and, at the same time, register some emerging and structuring relationships.

As shown by some authors listed in this chapter, the current dwelling model is still strongly influenced by the Modern Movement and by some standards established in previous centuries. Accordingly, the matrix of the housing project has shown to be minimally open to the diversity of demands arising from the ways of living perceived in contemporary times. In this context, some authors also note that, in general, architectural production has not been able to explore opportunities for innovation that may emerge from the relationship between advances in information technology and the domestic space.

The justification for the choice of concepts arises from the need to compose a theoretical basis that supports the research. Ergo, the chapter brings domesticity to bear on what concerns the space of dwelling—the house as a focal point—framing the research space. Cybernetics is the field that studies communication and control processes, especially between humans and machines. Finally, AI is understood as a set of mathematical models that can facilitate and enable this interaction process.

Throughout this chapter, the main goal is to offer a historical, conceptual, and critical understanding of these themes. As a result, the chapter aims to relate and establish more specific chains where these topics intertwine, forming a conceptual framework (see *Figure 1.1*) to support the research and the digital window concept proposed in Chapter 2.

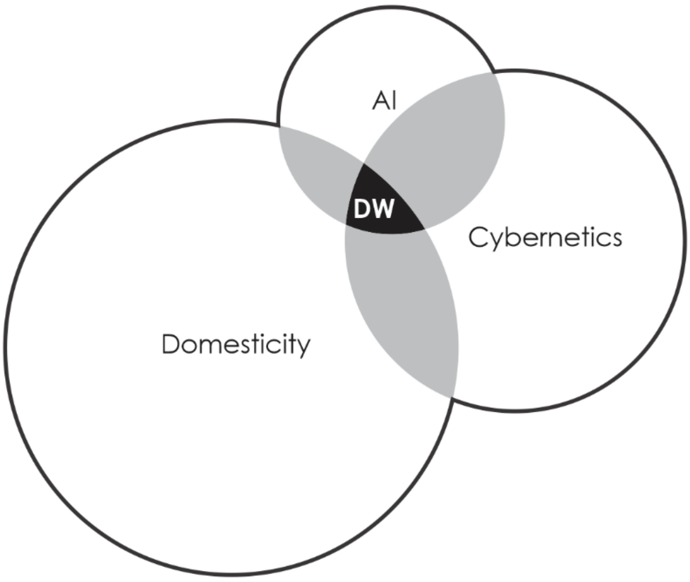

Figure 1.1 *Structuring concepts and relationships*

The method used to prepare this chapter is the literature review (Wang & Groat, 2013, pp. 142–143). Therefore, based on a set of information identified and raised about each topic, its continuity is divided as follows:

a) “Domesticity” (1.2): deals with the emergence and evolution of the concept of domesticity in Western society. In sequence, it addresses the diversity of ways of living and some critical issues observed in contemporary times. Among these, the issue of population aging stands out. Finally, the concept of aging in place is introduced.

b) “Cybernetics and AI” (1.3): includes the definition of cybernetics, its origin, and chief concepts. It follows some developments in cybernetics and brings authors who relate them to architecture. Some architects and projects exemplify this emergence of a systemic comprehension of architecture. Furthermore, the emergence of artificial intelligence as regards cybernetics, as well as the study of different approaches that each area assumed. Finally, the section presents a historical and general view on the development and definition of AI (contextualizing this topic to approach machine learning, natural language processing, and computer vision in Chapter 4).

With the grouping of these themes, the proposed connections, and the respective relevance of these concepts within the approach developed, this chapter delimits and contextualizes a broad theoretical framework around digital window concept. Hence, "Chapter 1 - Domesticity, Cybernetics and AI" paves the way for the discussions and concepts introduced in "Chapter 2 - Digital Window Framework."

1.2 Domesticity

1.2.1 A Brief Historical and Conceptual Contextualization of Domesticity

Domesticity arises from human interaction and activity (Rybczynski, 1986/1989, p. 53) and, to some extent, comes to determine what belongs to the human domain. The Latin origin of the word "domesticity" comes from *domesticu*, a derivation of *domus*, which means "house," already evidencing the proximity between the concept and dwelling space (Nascentes, 1966, p. 253). However, in Latin, *domus* also refers to "domain." Therefore, just as an animal or a vegetable can be domesticated through human coexistence and convenience, space can also become domestic depending on the human intention, need, and intervention.

Inhabiting is a fundamental condition of humanity, and its attachment to a specific building—to a house—is especially noticed after humans settled on land and developed agricultural skills (Harari, 2014/2020, p. 140). It has, since then, converged between permanencies and transformations. Investigating domesticity in Western society is also seeking to understand how and in what context the house begins to be transformed into a single-family dwelling unit, a pattern widely spread and reproduced by the Modern Movement and still dominant in contemporaneity (Marques Pereira, 2004).

During the Middle Age, the house had a much more collective aspect, with non-specialized, multifunctional spaces, and was mainly linked to the bourgeoisie, as the nobility lived in palaces and the clergy lived in monasteries (Rybczynski, 1986/1989, pp. 36–37). The house was gradually and slowly transformed. However, in the seventeenth century, signs of association between the idea of privacy and the concept of family began to appear. According to Historian Nicole Castan (1985/2009), this period evidenced the domestication of the family. In France, for example, houses connected to a family nucleus and disconnected from the workplace started to emerge. For Witold Rybczynski (1986/1989), the seventeenth century witnessed the decline of the medieval social house and the idea of family, comfort, intimacy, and privacy began to be shaped, which only came to be consolidated between the eighteenth and nineteenth centuries.

To better understand the emergence of the concept of domesticity in the Western context, it is necessary to recognize that the concepts relating public and private[3] did not always occur as they are currently experienced. Throughout the eighteenth century, the notions regarding the public and private spheres became increasingly distinct (Perrot, 1985/2009, p. 17). For Historian Philippe Ariès[4] (1985/2009), some dimensions must be taken into account to perceive this change. One of them is the opposition between the public person and the private person; and, consequently, what concerns the domain of the State, hence public, and in opposition to what concerns the particular sphere, which, ultimately, would shape the domestic space. Historian Michelle Perrot (1985/2009) adds that what had a public character ceased to allow, to a certain extent, private behavior; and came to represent the State—or what was State property—, while the private began to lose its negative, individualistic connotation, being gradually associated with a familiar and, therefore, more intimate sense.

Both Gonçalo Furtado & Inês Moreira (Furtado & Moreira, 2001) and Rybczynski (1986/1989) point out that the eighteenth century saw the consolidation of bourgeois individualism, whose spatial expression is evidenced by the emergence of more specialized intimate spaces such as, for example, bedrooms (the couple's room, the children's room), dining room, living room, private libraries, among others.

Rybczynski (1986/1989) singles out the eighteenth-century Georgian country house in England as an example of these transformations. The house is no longer a collective and public space for work, as it was characterized in the medieval period, becoming a place of leisure and contemplation, with increasingly specialized, individualized, and private spaces (p. 115).

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[3] The relationship between public and private will be an important theme in "2.2.1 Blurring," especially from the twentieth century onwards.

[4] Philippe Ariès (1914–1984).

The then-new dimension of private space enabled the flowering of intimacy that, together with domesticity, is considered by Rybczynski (1986/1989, p. 85) the greatest breakthrough of the Bourgeois Era. Also, according to Rybczynski (1986/1989), as a result of transformations throughout the eighteenth and nineteenth centuries, houses began to shelter a reduced number of people, becoming smaller and more intimate. Accordingly, the house ceases to have the exclusive function of refuge and protection, and starts to represent the family aggregation, understood as a new compact social unit.

In the 1800s, the house was already fully consolidated as a property for protecting the family's privacy and its social position. The house was the refuge of the ruling classes against the chaos of the city. The expression "*mur de la vie privée*" (walls of private life) comes from this period since, at that time, some defended walls as necessary elements to maintain the right to privacy (Perrot, 1985/2009). Sandra Marques Pereira (2004) indicates the French aristocratic palace of the seventeenth century as the primary reference for the bourgeois house that emerged during the nineteenth century, where the privatization of the family and the nuclear relationship were materialized (p. 79).

Therefore, after consolidating changes during the nineteenth century, it is possible to understand domesticity in the housing context as a result of human activity related to privacy, the idea of family, and how these elements relate to the space of the house. For Rybczynski (1986/1989), the consecration of the home comes precisely from this relationship between living space and family intimacy, aggregating and shaping these relationships spatially.

Throughout this evolutionary process, Rybczynski (1986/1989) highlights the role of women, both in the consolidation and in the formatting of bourgeois domesticity, stating that the house has become a female environment or under female control (p. 84). Castan (1985/2009), on the other hand, sees women as subordinate to their homes, not being assigned social roles of political, administrative, or corporate representation. Moreover, Marques Pereira (2004) takes an even more complex view about gender inequality in domesticity. For the author, bringing the children's room closer to the master's room (which took place in the eighteenth century) is a way to reinforce the responsibility of parents, especially the mother, in caring for their children; she also perceives a gender division in domestic spaces, with private and service spaces being regarded as the female ones, while the more public area and spaces for representation were the male ones (Marques Pereira, 2004, pp. 79–80).

This gender issue, the privatization and individualization of domestic spaces, among other social relations, contributed to formatting the model introduced by French Architects Viollet-Le-Duc and César Delay in the second half of the nineteenth century. This model was based on the tripartition of domestic activities and was implemented to reinforce the bourgeois way of life. The proposal quested to organize the domestic interior based on three sets of activities with different natures: 1) activities related to the public dimension of domestic life, such as receiving guests; 2) activities related exclusively to the family nucleus, more private and intimate; and 3) activities related to domestic services (Eleb & Debarre, 1999, as cited in Marques Pereira, 2004, p. 80).

Also, according to Marques Pereira (2004, p. 80) and Professor Marcelo Tramontano (1997, 1998), it is precisely this organization that will lead to the triadic zoning, dividing the house into (1) social zone, (2) private zone, and (3) service area, which will be a structuring logic to the twentieth-century modern house. However, before that, even during the nineteenth century, a parallel process regarding the increasing mechanization of society would be observed as a consequence of the English Industrial Revolution, and which began to penetrate domestic life, with the idea that machines could produce comfort and be used in the home[5] (Giedion, 1948; Rybczynski, 1986/1989, p. 144; Teyssot, 1994).

Rybczynski (1986/1989) proposed an evolutionary perspective of equipment and machinery destined for the domestic space where, until the seventeenth century, the popularization of glass and the use of chimneys (even if still rudimentary) deserve mention. In the nineteenth century,

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[5] As it will be showed later, this domestic mechanization is also partly linked to the role of women in the home.

ventilation equipment and gas lighting started to spread in some localities, even though presenting considerable problems. Nevertheless, within a three-decade period, from 1890 to 1920, the maturity of specific techniques combined with a search for innovation allowed houses to have central heating, internal pipes running hot and cold water, electric light, and electricity (Rybczynski, 1986/1989).

These innovations became popular from 1920 onwards and collaborated to consolidate the triadic zoning in the twentieth-century housing unit since the kitchen and bathroom were then physically integrated into the body of the house. The modernist housing model derives from many factors, ranging from social changes arising from the industrial revolution, passing through artistic, ideological, and political revolutions, to the housing shortage brought by World War I and II, among other events. However, for the sake of focus, these topics shall not be discussed.

Concerning domesticity, the aforementioned triadic zoning is established both in housing units aimed at the large working masses and in isolated modern houses, which cater to the public with greater purchasing power. Rather than being an artifice for class equality, this permanence is a means of assimilating the nineteenth-century bourgeois model, underlyingly establishing a functional matrix and a unique family pattern in all social strata (Marques Pereira, 2004).

Thus, the program of a minimum house proposed by the Modern Movement, according to Marques Pereira (2004), is composed of a living room (social area, coming from the junction of the living room and dining room), bedrooms (for couples and children, separated by gender), bathroom (private area), and a kitchen (service area). This program also requires that the house have minimal health conditions as well as access to solar radiation, potable water, and natural ventilation when desired (Marques Pereira, 2004). This model, proposed in that historical context, brings significant advances. Although, it concurrently seeks to consolidate a hygienist vision, centered on a typical man, with a typical family, of a society based on order and homogeneity (Colomina, 2006; Marques Pereira, 2004).

Marques Pereira (2004) registers the German influence from *Neues Bahuen*[6] (New Architecture) in the formatting of modernist premises, listing three relevant points on which are mentioned some possible developments:

- *Existenzminimum*: The delimitation of a minimal habitat within the modernist precepts that were still being consolidated. Based on this concept, a minimum set of social, functional, and, consequently, dimensional needs were safeguarded (Marques Pereira, 2004, p. 85). As an example, the work of the Portuguese Architect Nuno Portas (1969), *Funções e Exigências de Áreas da Habitação*, is one that, in some way, represents a result of this type of modernist approach.
- Attempt to standardize domestic activities through scientific studies: Including, but not limited to, anthropometric and ergonomic issues. To some extent, such scientific investigation resembles the process of incorporating Taylorism principles into the functionalist practice of modernism (Marques Pereira, 2004, p. 85). For instance, both Siegfried Giedion[7] (1948) and Rybczynski (1986/1989) approach Taylorism when discussing the mechanization of the domestic space in this period.
- *Laboratory kitchen*: Also known as *Frankfurt kitchen*, it is the basis of contemporary equipped kitchens and stems from a standardized modular logic with intense domestic mechanization. It aims to facilitate and streamline the daily activities in the kitchen, allowing for easy maintenance of its order and hygiene (Marques Pereira, 2004, p. 85). This type of modern kitchen can be understood as a female demand registered between the nineteenth and twentieth centuries (Giedion, 1948) and as an element among other factors that favored the insertion of women into the labor market (Rybczynski, 1986/1989). In a more critical view, Elizabeth Diller & Ricardo Scofidio (1994) consider it an instrument for exploitation and gender

[6] Or *Neues Bauen* (also translated as “New Building”). The group was composed, among others, by Bruno Taut, Ernst May, Hannes Meyer, and Walter Gropius and were very influential in the beginnings of the Modern Movement in Germany (Marques Pereira, 2004).

[7] Here it is used the spelling as presented in the book *Mechanization Takes Command* (Giedion, 1948), however, the correct spelling in German is Sigfried Giedion.

subordination since it keeps women at the core of domestic work (p. 41).

Issues such as the rationalization of the domestic space, and the search for efficiency, standardization, and hygiene in the house, are themes that impacted and continue to impact the daily life at home. The incorporation of the bathroom, for example, is considered an achievement of modernist architects and represents this search for a strictly functional, small, and aseptic space, where the body follows a hygienist logic (Marques Pereira, 2004, p. 87). As an example regarding the dissemination of the Modern Movement precepts and their possible problematic implications, some authors record this same concern with hygiene, described as a real obsession (Colomina, 2006; Diller & Scofidio, 1994).

Once the theme of dwelling became the referential matrix for the Modern Movement, its great penetration in society and even the permanence of many of its precepts became understandable. Nevertheless, characteristics such as the disregard of the place in relation to the universal, excessive standardization, the imposition of a standard man, and a standard model has proved to be inconsistent with the plurality of society and its different ways of living. Concerning domesticity, Marques Pereira (2004) proposes a critical reflection as she states that in the field of urbanism, modernist premises that proved inadequate are revised or surpassed, but that the same is not always observed about the house interior, where the current pattern, with exceptions, remains linked to the modernist matrix, its familiar model and homogeneous view of the world (p. 91).

1.2.2 Ways of Living

The proposed approach regarding ways of living is based on the formulation that, in contemporary times, a growing number of demands from society have gained expression and representation. The regnant housing typology does not always comprehend such demands. What the housing market has produced is still strongly connected to a generic model tied to the legacy of the nineteenth century’s ideological debates, emphasizing homogeneity (Marques Pereira, 2004, p. 92).

About the time frame, this research uses the term contemporaneity as proposed by the Italian Philosopher Giorgio Agamben (2006/2009). Then, it is understood that approaching contemporaneity is, at the same time, dealing with the present, though without being restricted to the immediate. In other words, being aware that the now is a synthesis of the past, constantly cracked and crossed by concerns and changes leading to the future (Agamben, 2006/2009).

For architecture to become more attentive and sensitive to the particularities of the new social demands that are imposed, it is necessary to reflect on contemporary lifestyles (Marques Pereira, 2004). Furthermore, even if housing is the theme par excellence of this reflection, the approach to contemporary issues must be multidisciplinary and diversified. Ultimately, it is essential to note that, in specific contexts, architects need to rethink the project focus, and the issue about the interaction between inhabitant and space gains relevance (Tramontano, 2007).

In order to understand the current plurality of ways of living, it must be accounted that, in contemporary times, longevity has reached unprecedented levels, and, simultaneously, new patterns of behavior have been expressed more freely than in the past. For example, never have so many people with so much freedom and lifespan to decide how to establish their affective, matrimonial, sexual bonds, among others (Rojas Marcos, 1992, as cited in Fernández Lorenzo, 2012, pp. 60–61).

As an example, the *Atlas Social de Lisboa* (CML, 2017) contemplates this transformation, mentioning that recent changes regarding life in society, especially during the last two decades, had led to modifications in family structures, emerging new forms of family aggregation and a greater diversity of arrangements. It also registers that the traditional family pattern has been losing importance in contemporary society, given the new types of structuration, which are characteristic of a society with a high degree of urbanization, as is the case of Lisbon.

According to Architect Pablo Fernández Lorenzo (2012), it is possible to split the main changes that demonstrate contemporary ways of living into five categories:

- *Work*: The author points out the incorporation of women into the labor market, the growing flexibility and transience of the labor market, the impact of technologies on the way and place of work, and the establishment of the home as a place of work, exercised remotely.

- *Population pyramid*: The inversion of the population pyramid is verified due to the increase in longevity and drop-in birth rates, generating a constant increase in older and retired adults (a critical phenomenon to this research).

- *Family nuclei*: Regarding changes in family nuclei, a lower number of marriages and an increase in divorces, a growing number of children who move due to separations, and the legal tendency to grant shared custody of children in these cases is noticed. Also, an increment in homes formed by second marriages, with children from previous relationships, alteration in the division of domestic tasks, couples without children or with only one child. The non-understanding of motherhood as a female obligation and a greater involvement of the father figure in raising children. The house starts to accommodate different rhythms of life for the family members. New technologies like the center of the home, new social media. Shopping in hypermarkets, the height of leisure time entertainment, and tourism as a collective holiday ritual.[8]

- *Coexistence units*: A larger portion of people living outside the traditional family pattern. With the increase of single-parent homes and same-sex couples. A more significant number of people living in single-person spaces, cohabitations, or even shared houses.

- *Living place*: There is a significant increase in individual dwellings. An obsession with safety and less coexistence between neighbors. The assimilation of some strategies from modernist projects, such as integrating specialized rooms (especially living room and kitchen)

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[8] Many of these behaviors are also verified in *Flesh: Architectural Probes*, by Elizabeth Diller and Ricardo Scofidio (1994). The different behaviors are presented as elements of contemporaneity that contextualize the works of art and architecture developed by these architects. See footnote 57.

and large openings with glazed windows (Fernández Lorenzo, 2012, pp. 52–53).

All these phenomena registered by Fernández Lorenzo (2012) show significant changes in the way society has been organized, being each day more diverse, centered on individuality, and, in a way, less constrained by a single pattern of behavior. Nevertheless, it is clear that architecture, especially as regards housing, has not always followed these transformations (Marques Pereira, 2004; Tramontano & Benevente, 2004). However, Tramontano (1997, 1998) ponders that one cannot have the illusion of having a prototypical isolated model that could meet all contemporary society's demands. On the contrary, the needs are diverse, and the nuances plentiful.

Furthermore, combinations of factors can happen, leading to different ways of life and, therefore, demanding other ways of living (Tramontano, 1997). For example, when analyzing factors related to contemporary ways of living, such as the tendency toward individualism and longevity, complexities that architecture cannot ignore may arise. In this context, it is possible to imagine the growing number of people living alone because they chose not to get married (individualism), and, as a young people, they have a profile of needs; however, there is also a growing group of individuals who live alone because of widowhood at an advanced age (longevity), and, consequently, with a different profile of needs. Not to mention that those who choose to live alone since youth also age and probably have different spatial expectations from those who only experience isolated living from the moment of widowhood.

The purpose of this example is to illustrate that the issue regarding ways of living is complex and should not undergo a reductionist and archetypal approach, at the risk of, to some extent, ending up reproducing an exclusionary standardization (Tramontano, 1997). Nevertheless, in contrast, this plurality of demands can be understood as a design matter, and the greater the complexity, the greater the specificity of the response, influencing the quality of the architectural project (Tramontano, 1998).

Within the varied contemporary demands exposed, this research turns to the question of population aging; as previously mentioned, people have never lived as much as they have in contemporaneity (Rojas Marcos, 1992, as cited in Fernández Lorenzo, 2012, p. 60). In proportions and numbers never reached before, the aging of society places architecture to face unique and innovative challenges.

Accordingly, to think the dwelling based on older adults and understanding their limitations and plurality can foster new paradigms as well as demanding that architecture redefines standards to interpret complexities that architects have often neglected. Thus, recognizing the phenomenon of population aging and analyzing data and concepts that emerge in this scenario is relevant for this research.

1.2.3 Population Aging

Population aging is an indisputable phenomenon verified throughout the world, and its record occurs even more dizzyingly and radically in industrialized economies. Several authors see a variety of different factors as responsible, mainly the combination of increased longevity with a reduction in the fertility rate (Gabinete de Estratégia e Planeamento, 2017, p. 5; Matias, 2016b, p. 17). Additionally, in some countries (mainly in the United States of America [US]), the phenomenon is intensified by the aging of the generation known as *Baby Boomers*, which refers to those born in the demographic explosion that occurred right after World War II (Coughlin, 2019, p. 33).

Population aging is a highly impactful demographic phenomenon, as "life expectancy in industrialized economies has gained more than 30 years since 1900, and for the first time in human history there are now more people over 65 than under 5" (Coughlin, 2019, p. 33). Though, identifying its impact on society (economically, socially, and culturally) is a complex task, even having several quantitative projections that seek to forecast the situation in the coming decades.

In this context, concerning the situation within the US, the document *Projections & Implications for Housing a Growing Population: Older households 2015–2035* (Joint Center for Housing Studies of Harvard University, 2016), presents the following data:

> The next two decades will bring substantial growth in the number of older adults (defined here as those aged 65 or over). With the leading edge of the large baby boom generation (born 1946–1964) now passing age 70, the US Census projects the 65-and-over population will increase by more than 30 million people by 2035 to reach 79 million, with more than half that growth occurring in the next decade. The 80-and-over population alone will double between 2015 and 2035 from 12 million to 24 million, with 70 percent of that growth occurring from 2025–2035, the decade during which the leading edge of the baby boomers passes age 80. Overall, this growth will shift the age distribution of the U.S. population so that by 2035, one in five people in the US will be aged 65 and over, up from one in seven today. (p. 5)

These projections demonstrate that the situation of population aging, which already presents unprecedented numbers in history, tends to intensify even more vertiginously in the next decades. According to data published by the Ministério do Trabalho, Solidariedade e Segurança Social de Portugal (Gabinete de Estratégia e Planeamento, 2017), organized in the report *Terceiro Ciclo de Revisão e Avaliação da Implementação do Plano Internacional de Ação de Madrid sobre o Envelhecimento (MIPAA)*, the Portuguese situation, proportionally, differs little from other developed countries. In 2015, almost 20% of the Portuguese population was comprised of older adults, representing 2.1 million people. This source also estimates that such portion of the population will increase to 26% by 2030 and 29% by 2060 (p. 5). To Ana Fernandes (2014), Portugal is one of the most aged countries globally.

The provisional report provided by the INE, on the “Censos 2021,” points out that the Portuguese population aged 65 or above has already reached 23.4% of the total, while the population between zero and 14 years old corresponds to 12.9% of the total (INE, 2021a, p. 6). In light of this, there is a worsening of such phenomenon known as *double aging*, consisting of a concomitant reduction in the younger population and an increase in the older population. Furthermore, the same report points out that the *Aging index*—number of people aged 65 and over for every group of 100 young people between zero and 14 years old—is at 182, that is, 182 persons aged 65 and over for each group of 100 persons between zero and 14 years. In “Censos 2011,” it was 128, while in “Censos 2001,” it was 102 (INE, 2021a, p.

8), and, according to the report *Projeções de População Residente: 2018–2080* (INE, 2020b), it is expected to reach 300 in the year 2080 (p. 1).

Another issue that stands out is the consequent increase of even older people, who often demand greater attention and assistance from the State. In 2015, 614,000 people were 80 years old or more in Portugal, and for 2060 this number is expected to be higher than double, reaching 1,421 thousand people (Gabinete de Estratégia e Planeamento, 2017, p. 5). Even with different time frames, this data confirms the trend previously cited by the *Joint Center for Housing Studies of Harvard University* (2016) regarding the growth in the number of people aged 80 years or more in the US, highlighting the globality of this issue in the most developed economies.

The *Atlas Social de Lisboa* (CML, 2017), prepared by *Câmara Municipal de Lisboa - Pelouro dos Direitos Sociais*, published in 2017,[9] confirms this phenomenon and presents more specific details about this scenario, reporting that almost a quarter of the Lisbon population is already made up of older adults (see *Figure 1.2*). Furthermore, when the metropolitan area of Lisbon is analyzed, it is possible to see that, in 2011, the Aging Index was 117, and in 2021 it reached 151, confirming the growth trend seen in the rest of the country, even if with slightly lower numbers (INE, 2021a, p. 8).

Within the group of older adults in Lisbon, 85,000 lived alone or with another individual of the same age group. However, by analyzing this data in more detail, it is possible to verify that 40% (35,000 individuals) were widowed women who lived alone (CML, 2017), accentuating the need for a more specific look at the gender issue related to the domesticity of older adults.

Some parishes in Lisbon concentrated even more strongly the population aged 65 and over (see *Figure 1.2*), and the seven parishes with the highest proportion of older adults were, respectively: Olivais (29.8%), Ajuda (29.5%), Benfica (29%), Alvalade (28.8%), Alcântara (28.7%), São Vicente (27.9%), and Campo de Ourique (27.6%). It is noticeable that the

[9] The *Atlas Social de Lisboa* was published in 2017; however, the data presented referring to population aging are from the “Censos 2011,” under the responsibility of the INE (Statistics Portugal).

greatest concentration was in the parishes surrounding the historic center, with a tendency to increase towards the north. Depending on when the dwelling stock was built, many of these regions lack the urban and architectural conditions suitable for this age group (CML, 2017).

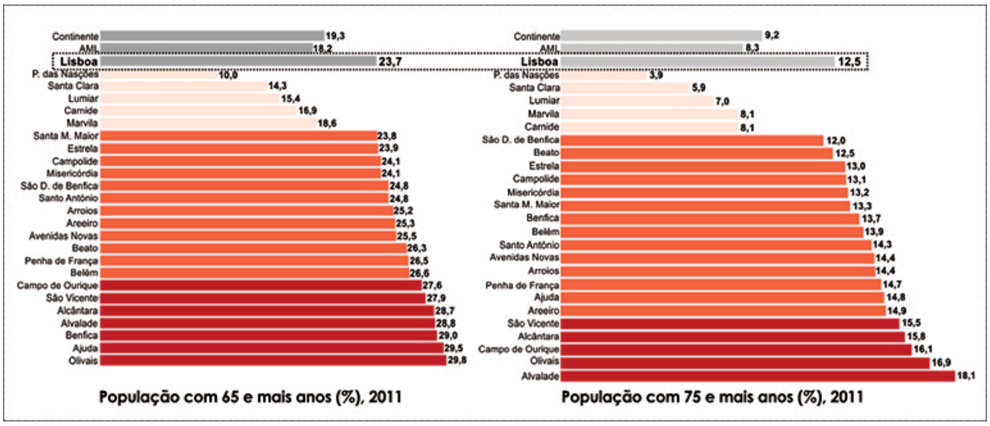

Figure 1.2 *Population aged 65 or over, and aged 75 or over from Lisbon (adaptation of data from INE, "Censos 2011," as cited in Atlas Social de Lisboa, 2017)*

In addition to the inadequacies presented, whether in the city or at the house, both Patrícia Matias (2016b, p. 142) and Joseph F. Coughlin[10] (2019, p. 34) point to another type of problem commonly faced by older adults: stereotyping. The image commonly accepted by the society of a fragile, dependent, and inactive individual contributes to stigmatizing this significant portion of the population. This profile represents a pattern that often does not correspond to reality.

This significant cohort, in constant expansion, has its specific needs concerning various aspects of life in society and, for this reason, requires greater attention and specialized policies. When it comes to architecture, the challenge is immense. Several studies have been carried out in recent decades, besides many others currently under implementation, especially regarding ergonomics and mobility. Unfortunately, such studies usually have a palliative approach or are based on the stereotype mentioned hereinabove and frequently reinforce it (Coughlin, 2019).

A fact that highlights the importance of a more sensitive architecture for this population is that "some 87% of people over 65 say they'd prefer to 'age in place' in their own homes" (Coughlin, 2019, p. 36). Even if the data

[10] Director of the MIT *AgeLab*.

refer to the U.S. reality, in Portugal (and in several other countries, according to the World Health Organization [WHO], 2016), the number of people who prefer to enjoy the right to age in their own space also constitutes the majority, as long as the space has conditions to do so. This reality requires that these spaces have domestic qualities capable of welcoming, adapting to, representing, and protecting this public (Lecovich, 2014).

To understand the issue of population aging as a problem means disregarding that this situation results from many social, economic, and scientific advances (Fonseca, 2018, p. 8). Being able to transform the majority desire to age in place into a good possibility, and not just in the only feasible solution (World Health Organization, 2016, p. 35), is a multidimensional challenge, where the house is not the unique element in question; however, it is still a fundamental part in this process. Thus, thinking of a domestic space capable of supporting the specific needs of older adults, alleviating any loss of abilities due to the aging process, or even stimulating a more active aging, are significant and pertinent contemporary themes in architecture.

1.2.4 Aging in Place

The concept of *aging in place* refers to being able to grow old at home, within the community one belongs; and, in general, it comprises the right and the possibility of aging in their own home, or in the same community, without the need for, or postponing as much as possible, institutionalization due to problems related to the aging process (Fonseca, 2018; Joint Center for Housing Studies of Harvard University, 2016; Lecovich, 2014; Matias, 2016a, 2016b; World Health Organization, 2016). As previously mentioned, this is the preference of the vast majority among older adults (Coughlin, 2019, p. 36; Fonseca, 2018, p. 9; Lecovich, 2014, p. 21).

António M. Fonseca (2018) argues that “Place,” in the sense of something that encompasses both house and community implies a highly relevant identity issue, as it ensures a sense of continuity capable of connecting different moments and stages of life. Maintaining this familiarity is a fundamental point in the AiP concept; however, in some contexts, such as areas with an intense gentrification process, eventually staying in the same house can be damaging, as several other links have already been broken (p. 10).

In this way, the AiP concept shifts the perspective about transferring the older person to other architectural types traditionally aimed at this audience, such as nursing homes, assisted or medicalized homes, for instance (Matias, 2016a). The house plays a fundamental role in the quality of life and independence of older adults and will play an increasingly prominent role concerning long-term care provision (Joint Center for Housing Studies of Harvard University, 2016). This standpoint is a growing trend for the coming decades, in a scenario where an increasing number of older adults remain in their homes and must, at the same time, face limitations and health problems that can arise with the aging process (Joint Center for Housing Studies of Harvard University, 2016, p. 4).

Nonetheless, the concept of AiP is broader, not restricted exclusively to the house. In the report of the *2º WHO Global Forum on Innovation for Ageing Populations*[11] about rearrangements aimed at older people, the five main areas of intervention in the AiP process were delimited, called "'Five Ps' - People, Person-centered services, Places, Products, and Policies" (World Health Organization, 2016). These areas quest to add new dimensions to the AiP issue, delimiting specific fields, but at the same time they aim to establish correlations among these axes.

This expanded understanding makes it evident that consideration for AiP to be more effective goes beyond the domestic sphere, in isolation, including neighborhood and other urban issues, sociopolitical aspects, and even the involvement of the industry and the market as a whole. Thus, in a coordinated effort, the objective is a symbiosis of multidisciplinary actions and in different spheres and scales. However, it does not exempt architecture from its responsibilities and possibilities as regards the house in this debate.

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[11] Event held in 2015 by the World Health Organization (WHO) in Kobe, Japan.

Intervening in the built space, seeking to adapt it to the needs that progressively appear, constitutes one of the alternatives with a less economic impact on the AiP process (Matias, 2016a, p. 80). In the US, this perception has given rise to educational programs, aimed at professionals in the construction industry, intended to make houses more sensible to the needs of older adults, such as, for example, *The National Association of Home Builders' Certified Aging-in-Place Specialist* (Joint Center for Housing Studies of Harvard University, 2016, p. 67).

Concomitantly, it is necessary to discern that "intervening in the built space" means being open to reformulate, improve, and adapt both the house and the urban space. As for the house, the rationale of intervention cannot be limited only to mobility issues, even though these are also highly relevant. Fonseca (2018) remarks that relatively recent innovations such as tele-assistance and remote home care, among other devices, can be important throughout the AiP process (p. 11). This type of action, of particular interest to this research, intends to increase safety within the domestic space besides promoting digital inclusion.

Digital inclusion, for example, can foster social interaction, leading to a more active life (Guimarães, 2021), delivering an improvement in health overall, and expand cognitive skills (Betts et al., 2019). Taking digital inclusion as a theme and considering the "Ps" idealized by the WHO[12] (2016), it is possible to devise a broad and relational proposal. Such a proposal could be based on household habits of older adults (People), creating services centered in the needs and possibilities of individuals (Person-centered services), including characteristics of domestic spaces already consolidated (Places), through the development of innovative products (Products). In this conjuncture, architecture could support leveraging strategies of AiP, helping to promote digital inclusion and enhancing the everyday domestic experience.

[12] This proposed framework does not include the "Politics" dimension, which is also one of the "five Ps," for the sake of research framing since this dimension requires a different scope of work than the one developed here.

In a context with limited public and private resources such as in Portugal, it becomes even more critical to search for innovative and inter-disciplinary solutions that recognize in AiP, additionally to an ideal concept, its strategic potential to formulate actions ranging from local and particular to regional and collective scales (Matias, 2016a, p. 84). At the local scale, architecture is a primary factor when the objective is to extend, as much as possible, the permanence of older adults in their own homes (being it a positive permanence and suitable to the individual's health conditions). Hence, maintaining integration with one's particular environment, marked by habits and places that have already been established, often over decades, and where one identifies and recognizes oneself. This is a highly valid and current task with which this research is committed.

1.3 Cybernetics and AI

1.3.1 A Brief Historical and Conceptual Contextualization of Cybernetics

Cybernetics is conceived as a field of science that studies control and communication (Lafontaine, 2004, p. 22), intending to cover a general theory of information processing, whether between humans and machines, machines and humans, as well as machines and machines (Wihart, 2015, p. 135). Additionally, the Philosopher Georges Vignaux (1991) describes *cybernetics* as a field of study that seeks to mathematically model processes related to information (p. 23). The first notions of cybernetics were verified in 1947, when Georges Canguilhem (1904–1995) presented a new way of understanding the idea of a machine based on the study of functions and structures of self-regulating living organisms (Yiannoudes, 2016, pp. 9–10). Then, in 1948, Mathematician, Philosopher, and Scientist Norbert Wiener (1984–1964) laid the foundations of cybernetics in his book *Cybernetics: Or Control and Communication in the Animal and the Machine* (1948/1994). Henceforth, he is considered its founder.

In his book, Wiener (1948/1994) justifies the choice of the term cybernetics, stating that the term, from the Greek *Κυβερνήτης* (*Kubernetes*), refers to the word “steersman” and is also related to the origin of the word “governor” (originated from the conversion from Greek to Latin). Additionally, the choice of the term still seeks to recognize the theoretical analysis of the feedback mechanism made by James Clerk Maxwell (1831–1879) in 1868 (pp. 11–12). Therefore, the theory of control and communication has been linked since its origins to the idea of feedback. Thus, governance, or control, is mediated by exchanging information in a similar process to what happens with a steersman, who controls the boat to reach a destination.

Both Vignaux (1991, p. 23) and the Philosopher Celine Lafontaine (2004, p. 32) perceive the World War II as a historical fact that marks the emergence of cybernetics. Lafontaine identifies a relationship between the desire for reparation of a scientific group that felt guilty for developing the atomic bomb,[13] with the establishment of a theory whose general objective is to combat *entropy*, a tendency to disorganize a system (p. 41). Furthermore, the observation of systems aims its regulation through the exchange of information (communication). Therefore, aware of the notions of entropy and information, feedback stands out as one of the key principles of cybernetics (p. 31).

A more organized and efficient information control process becomes necessary with an increasingly mechanized[14] and more complex society. Several concepts, including feedback, are added to the cybernetic theory. Considered an exceptional mathematician, according Lafontaine (2004), Wiener (1954/1967) uses probability to simplify information sharing, since the more likely the information contained in a message is, the less information is shared. However, to get a sense about the degree of probability, the system needs to resort to memory and feedback mechanisms.

For Wiener (1954/1967), *feedback* is responsible for the regulation of information processing to guarantee the fulfillment of the objective (*goal*), even if changes may arise (as the steersman does). The ability to receive and send information (*input* and *output*) provides the system with a combination of opposing states that allows for continuous adjustment (control) of actions. Also, according to Wiener, this information flow based on feedback generates a system marked by circularity (*loop*). As many combinations between inputs and outputs can occur, the memory capacity becomes essential for recording the successful combinations, facilitating access to the most appropriate information, consequently reducing the volume of data to be processed. Thus, the cybernetic control system (first order, as discussed later) is not based on expected behavior; above all, it is centered on the observed behavior, where the exchange of reactive information in feedback ensures the dynamic stability of the system (Brites, 2018, p. 34).

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[13] Lafontaine (2004) cites, for example, that John von Neumann (one of the most relevant mathematicians of the twentieth century and fundamental for the development of computation) was one of the members of the *Manhattan Project* and calculated at what altitude an atomic bomb should be dropped to maximize its destructive power (pp. 35–36).

[14] It is interesting to note that the book *Mechanization Takes Command: A Contribution to Anonymous History*, by Siegfried Giedion, was published in 1948, the same year of *Cybernetics: Or Control and Communication in the Animal and the Machine*, by Norbert Wiener.

Between 1946 and 1953, the ten meetings that were later known as *The Macy Conferences* took place, where renowned scientists from different fields of knowledge participated (Lafontaine, 2004, p. 38). Besides Wiener, the meetings included the participation of John von Neumann (1903–1957), Arturo Rosenblueth (1900–1970), Claude Shannon (1916–2001), Warren McCulloch (1898–1969), Paul Lazarsfeld (1901–1976), Ross Ashby (1903–1972), Alex Bavelas, Gregory Bateson (1904–1980), Roman Jakobson (1896–1982), Margaret Mead (1901–1978), and Heinz von Foerster (1911–2002), among others. Lafontaine understands this series of conferences as the inception of origin of cybernetics and highlights that the title of the first meeting, "Feedback Mechanisms and Circular Causal in Biological and Social Systems" (p. 36), already demonstrated the consolidation of the intention to shelter, under the same explanatory model, living organisms, machines, and society.

In the preface to his book *Understanding Understanding: Essays on Cybernetics and Cognition* (2003d), Biophysicist Heinz von Foerster describes the relevance and diversity of the members at the Macy conferences:

> The group included Norbert Wiener, who had coined the term "cybernetics"; Claude Shannon, the inventor of information theory; Warren McCullough, one of the leading neuropsychiatrists—he called himself an "experimental epistemologist"; Gregory Bateson, the philosopher and anthropologist; his wife Margaret Mead, the anthropologist who made Samoa famous; John von Neuman, one of the people who started the computer revolution; and many others of this caliber. (2003d, pp. vi–vii)

In addition to this group, the Cyberneticist Gordon Pask (1928–1996) is also noteworthy. His contributions include the deepening of systemic notions of uncertainty, adaptation (Pask, 1961), cognition, interaction, conversation, and learning (Pask, 1976), among others. According to von Foerster (2003d), Pask developed the first authentic cybernetic teaching machines (p. vii). The *Conversation Theory*, proposed by Pask (1976), in short, is developed around the observation and description of the interaction between two or more cognitive systems, aiming at mutual understanding.

In "Cybernetics of Cybernetics," von Foerster (1979/2003b) conforms the proposal of *second-order cybernetics*, cybernetics based on observation systems, and not only on observed systems which, in turn, configure *first-order cybernetics*. The author points to Pask as a cybernetician who was already working on these notions, even without using this terminology. Also, according to von Foerster, Pask distinguished two orders of analysis: one where the observer can stipulate the purposes of the system (first-order stipulation) and a second-order stipulation, in which the observer interacts with the system in such a way that it can stipulate its purpose, not just that of an exclusively observable system.

By expanding the role of the observer in the construction of systems, second-order cybernetics becomes an essential approach for further developments in the field of cybernetics (Yiannoudes, 2016). While in the first order the control mechanisms adjusted the behavior to reach a determined objective (homeostatic model[15]), the second-order mechanisms interact with the observer to reach an objective that becomes dynamic. Second-order cybernetics is based on positive feedback, with a significant increase in the volume information about the state of system parts and their interactions. This fact admits that more hypotheses of the system organization (or reorganization) can be processed, allowing for self-organization (autopoietic system). An *autopoietic system*,[16] in short, is a closed and autonomous system that can constantly reproduce and regenerate its parts.

According Socrates Yiannoudes (2016), complex control systems, such as *global positioning system* (GPS) guided automated steering systems, were modeled following a framework provided by second-order cybernetics. Aggregating of autopoietic principles to second-order cybernetics allows to understand and develop complex processes, which could involve models based on learning, self-organization, emergence, and conversational interaction among biological, social, or artificial systems.

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[15] The *Homeostat* is a mechanism capable of self-regulation by modifying its internal patterns. The mechanism was developed by Engineer Ross Ashby and aimed to reproduce the biological behavior of self-regulation (Lafontaine, 2004, p. 53). Russell and Norvig (2010), when pointing out the influence of cybernetics on the foundations of AI, say that Ashby believed it was possible to recreate the mind through homeostatic mechanisms (p. 15).

[16] According to Yiannoudes (2016, p. 14), second-order cybernetics found its inspiration sources in other scientific fields; however, it only reached maturity with the release of the book *Autopoiesis and Cognition: The Realization of the Living* (1980) by Humberto Maturana and Francisco Varela.

Such an approach has been the basis for several experiments and research in architecture, especially during the last three decades. For instance, Yiannoudes (2016) points to a representative group of contemporary architects and researchers who have resorted to cybernetic theory to develop experimental environments beyond homeostasis, seeking solutions based on more interactive models. These professionals and researchers continue, in some way, the precepts of the cybernetics pioneers, particularly the developments of Pask.

1.3.2 Interdisciplinarity and Architecture

Cybernetics pioneers intended to establish it as a science and believed they were formulating the theoretical structure of a "*scienza nuova*" (Lafontaine, 2004, p. 23), capable of supporting a broad spectrum of areas of knowledge. According to Lafontaine, Wiener himself introduced cybernetics as a science aimed at investigating the general laws of communication and their technical applications; Lafontaine mentions, as an example, the preface written by Wiener for the reissue of *Cybernetics: Or Control and Communication in the Animal and the Machine*, in 1961, in which he claims the status of science for cybernetics. Nevertheless, recognizing cybernetics as a science is not a consensus.

Lafontaine (2004) highlights that cybernetics stems from a problem about inaccuracies regarding definitions and terminology relevant to different areas trying to work together. Therefore, the issue of interdisciplinarity led to the need for seeking a highly comprehensive theoretical framework. The author mentions that at the first congress of Namur in 1956, Louis Couffignal (1902–1966)—a great cybernetics enthusiast in France—affirmed that the term "science" should be reserved for studying natural phenomena, which does not necessarily apply to cybernetics, since it has practical purposes. Hence, Lafontaine points to cybernetics as a matrix of technoscience, with an interdisciplinary scope and more related to operational control than to so-called fundamental research, i.e., understanding a given phenomenon (pp. 26–27).

Regardless of the controversy surrounding the term "science," what is remarkable when analyzing the origin of cybernetics is its interdisciplinary expression. Lafontaine (2004) identifies an intense mobilization and grouping of scientists from the most varied areas, demanded by World War II, as a movement that led to the approximation of apparently distant theoretical fields (p. 36). The list of renowned scientists who participated in the Macy conferences already showed its strongly interdisciplinary character, as Lafontaine and von Foerster (1991/2003c) attested. For von Foerster (1991/2003c), Macy conferences were a true manifestation of interdisciplinarity: "If you were to begin with Anthropology in an alphabetical list of academic professions, and end with Zoology, my guess would be that almost every one of these disciplines had a representative present" (p. 300).

Within such interdisciplinarity, Pask was the primary reference in bridging cybernetics with architecture. The cyberneticist was in favor of a "cybernetic theory of architecture" (1969, p. 74), offering guidance on applicable systems and delimiting concepts dear to this approach, like "performance," "conversation," "interaction," "environment," and "participation" (Haque, 2007). In his famous article, "The Architectural Relevance of Cybernetics," Pask (1969) quests to highlight a systemic approach to architecture and how it could find new ways to enrich its design processes as conception and as an interactive spatial experience. The author also remarks that:

> The high point of functionalism is the concept of a house as a 'machine for living in'. But the bias is towards a machine that acts as a tool serving the inhabitant. This notion will, I believe, be refined into the concept of an environment with which the inhabitant cooperates and in which he can externalise his mental processes, ie, mutualism will be emphasised as compared with mere functionalism. For example, the machine for living in will relieve the inhabitant of the need to store information in memory and the need to perform calculations as well as helping out with more obvious chores like garbage disposal and washing up dishes. Further, it will elicit his interest as well as simply answering his enquiries. (Pask, 1969, p. 74)

Pask's idea about mutualism is based on a vision of the built environment as a machine (in relation to the vision introduced by Le Corbusier) capable of interacting with the inhabitant and not just fulfilling a strict function having pre-programmed goals. Architect Usman Haque (2007), in his article “The Architectural Relevance of Gordon Pask,” cites four experiments by Pask that would intensify this approach: *MusiColour*, in 1953; *Self-Adaptive Keyboard Instructor* (SAKI), in 1956; Chemical Computers, in 1958; and, *Colloquy of Mobiles*, in 1968. Even though these projects by Pask do not specifically focus on architecture, they demonstrate undetermined and user-centered systemic processes. Such strategies can have implications in the architectural field.

Haque (2007), for instance, understands that “for an architecture built on sensors and actuators, SAKI provides a pragmatic strategy for constructing algorithms that have multiple dynamic environmental inputs and outputs” (p. 57). At the same time, the *Colloquy of Mobiles* project can be regarded as a staging of Conversation Theory (Haque, 2007, p. 60), to exemplify how an interactive system can be built (Haque, 2006).

Besides contributing directly with relevant names in architecture, such as Cedric Price (to be shortly approached later), Pask has been an essential reference for architects and researchers over the decades (Haque, 2007). Most prominently between the 1960s and 1970s, his developments (especially the Conversation Theory) influenced Architect Nicholas Negroponte. Negroponte was responsible for the *Architecture Machine Group* at MIT (now *Media Lab*) and author of the influential book *Soft Architecture Machines* (1975), whose introduction “Aspects of Machine Intelligence” was written by Pask. Between the 1980s and 1990s, Pask’s involvement with the Architectural Association School of Architecture (AA) in London had a strong influence on the education of Architect John Frazer, author of the famous book *An Evolutionary Architecture* (1995) with its foreword written by Pask. Frazer also collaborated with Price on the *Generator* project in 1978 (Furtado, 2008). Following this “Paskian chronology,” during the first decade of the 2000s, it is possible to include Haque (2006, 2007), who also attended AA and developed the installation *Open Burble* (2006), an interactive system that follows Pask’s cybernetic precepts.

In the early 1960s, likewise in the AA context, the Archigram group emerged. Through the publication of the homonymous magazine, the group divulged its ideals and projects, considered futuristic or even utopian. The

Archigram approached many cybernetic principles, mainly when exploring the exchange relationships between biological and technological systems, assimilating dynamic characteristics of the body to buildings, resulting in an architecture marked by indeterminacy and adaptability (Yiannoudes, 2016, p. 21). Also, according to Yiannoudes, the adaptable nature of the projects would be a strategy to accommodate the diversity of human needs, going against the homogenizing pattern conceived by the Modern Movement (p. 19).

Cedric Price[17] (1934–2003) is probably the utmost reference in architectural production that came closest to the cybernetic principles of the 1960s and 1970s. His projects, *Fun Palace* (1962) and *Generator* (1976), are relevant and constant references for works dedicated to cybernetics in architecture. The *Fun Palace*—a project aimed at entertainment and free time—gained considerable prominence, despite not having been built (Brites, 2018).

With the ambition of providing the *Fun Palace* with mechanisms that would enable it for adapting to a program that dealt with a certain degree of indeterminacy, Pask joined the cybernetics subcommittee of the project in 1963 (Mathews & Colleges, 2005, pp. 82–83). Pask (1969) himself makes reference to this project in his aforementioned article "The Architectural Relevance of Cybernetics" (p. 73). According to Mathews and Colleges (2005), in 1964 Pask highlighted the project systemic approach by listing nine areas of cybernetic intervention where mathematical models to support the program specificities would be required. These include the provision of collective and individual interactive activities (using teaching machines by Pask); considerations about visitation patterns, audience capacity and architectural adaptation mechanisms corresponding to flow sweeping; communication and information systems; cyber arts; and philosophical questions to explore the relationship between organization and happiness, with possible

[17] Price is commonly associated with Archigram, but he was not officially part of the group (Brites, 2018). However, Price had relationships with members of the group and shared the same intellectual and cultural background (he graduated from AA, where he soon became a professor).

implications for leisure in an automated society (Mathews & Colleges, 2005, p. 84).

Hence, Yiannoudes (2016) acknowledges the *Fun Palace* as a matrix that accommodates an interactive machine, where both observer and the observed system are parts of the same system, configuring a second-order cybernetic approach (pp. 28–29). The *Fun Palace*'s design is also emblematic in understanding the design process as a second-order cybernetic process, where the architect—in the case of *Fun Palace*, supported by an interdisciplinary team—controls the design of the control systems. This position is in line with the view of Pask (1969) when he states that “the designer is controlling the construction of control systems and consequently design is control of control, i.e., the designer does much the same job as his system, but he operates at a higher level in the organisational hierarchy” (p. 76).

For Haque (2007), the argument that Pask's developments and the pioneering cybernetic approaches in architecture were far ahead of their time and, thus, did not have broad assimilation within the architectural community (p. 54). However, these efforts shaped the conceptual and practical bases of projects aspiring to be responsive, dynamic, and interactive. There was a growing interest in this universe between the late 1990s and the first decade of the 2000s (Carpo, 2013). Such movement was driven primarily by the advances and popularization of computing and the internet. Several authors[18] have focused on these themes, and at least two editions of the journal *Architectural Design* (AD) recorded numerous architectural experiences that explored the systemic and interactive approach to architecture (Yiannoudes, 2016, p. 3). Most of these and other architectural experiments published in the *AD* journal were grouped in the book *The Digital Turn in Architecture 1992–2012* (Carpo, 2013).

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[18] Yiannoudes (2016, p. 3) lists Kas Oosterhuis's books *Architecture Goes Wild* (2002), *Programmable Architecture* (2002), and *Hyperbodies: Towards an E-motive Architecture* (2003); *iA#1 – Interactive Architecture* (2007) by Kas Oosterhuis, co-edited with Xin Xia, and *Hyperbody: First Decade of Interactive Architecture* (2012) also by Kas Oosterhuis, co-edited with Henriette Bier, Nimish Biloria, Chris Kievid, Owen Slootweg, and Xin Xia; the book *Interactive Architecture* (2009) by Michael Fox and Miles Kemp. Moreover, the journals “4dspace: Interactive Architecture” (2005) and “4dsocial: Interactive Design Environments” (2007) were both edited by Lucy Bullivant. The article mentioned earlier, “The Architectural Relevance of Gordon Pask,” by Usman Haque, was published in this 2007 edition. Most recently, it is also possible to correlate works such as *Robot House: Instrumentation, Representation, Fabrication* (2017) by Peter Testa with this workflow.

In any case, it is significant to bear in mind that, regardless of the technological means used, the search for an interactive architectural process based on a cybernetic apparatus must consider the inhabitant as the central element of the system. Consequently, establishing a bottom-up approach, concerned with creating a more productive, mutual relationship focused on the inhabitant's needs and habits, assuming the leading role in the configuration and evolution of their own space (Haque, 2007, p. 61).

From this cybernetic approach to the project, architecture emerges endowed with a certain type of intelligence, manifested through its second-order control systems, with its action centered on the inhabitant and mediated by dialogue (in a sense structured by Pask). For Pask (1969), these control systems must be a peculiar mixture, capable of operating both as catalysts, crutch, memory, and arbiter (p. 76). Thus, when architects resort to cybernetic concepts and principles, they aim, above all, to expand the architectural repertoire in the search for setting up systems capable of sheltering the inhabitant in a more idiosyncratic way.

1.3.3 Cybernetics and Intelligence

Apart from the great effervescence surrounding cybernetics in its first decades, and even though advances were being promoted and consolidated over the following decades, some assess it as an outdated and forgotten theoretical field. Nevertheless, Lafontaine (2004) considers it paradoxical that such supposed forgetfulness is precisely the proof of its cultural assimilation, where concepts such as "cyberspace" and "cyborg," for example, are already incorporated into the collective imagination (p. 22). The most varied fields boosted by cybernetics somehow consolidate, update, and perpetuate its concepts (Johnston, 2008, p. 61).

Lafontaine (2004) lists automation, cognitive science, informatics, artificial intelligence, prosthetics, and even areas such as molecular biology and genetic engineering as fields that, at their origin, can be related to cybernetics (p. 22). Within this set of knowledge areas, many authors credit the emergence of AI as part of the cybernetics legacy (Brites, 2018; Johnston, 2008; Lafontaine, 2004; Russell & Norvig, 2010; Yiannoudes, 2016).

However, it is relevant to realize that despite cybernetics and AI have converging points besides understanding that intelligence can emerge from non-organic means, they pursue intelligence in different ways (Johnston, 2008).

Intelligence is a complex and slippery concept (Oliveira, 2017, p. 88). Defining intelligence, and even measuring it, was a challenge pursued by cyberneticists from the outset. Lafontaine (2004) points out that the "3rd International Congress on Cybernetics," held in 1961, already had the objective of trying to infer how the brain functions to build intelligent machines (p. 23). Before that, in 1948, in the aforementioned inaugural book *Cybernetics: Or Control and Communication in the Animal and the Machine*, Wiener (1948/1994) had already spoken openly about the "mechanization of processes of thought," "*machina ratiocinatrix*" (p. 12), and "artificial memories for the machine" (p. 14), for example.

Lafontaine (2004) defines *intelligence* in cybernetics as the ability to guide and regulate actions based on feedback and pursued goals (in a first-order context). Conversely, Pask (1975) argues that intelligence is only possible through conversation (in a second-order context). Nevertheless, for Pask (1975), information is not just something to be transmitted between parties, but an exchange that results in mutual understanding: "Intelligence is a property that is ascribed by an external observer to a conversation between participants if, and only if, their dialogue manifests understanding" (pp. 7–8).

In the cybernetic paradigm, intelligent machines are only feasible due to the existence of *memory*, which is understood as a reproducible structure for processing information, capable of operating information storage and exchange (Lafontaine, 2004, p. 50). Accordingly, Wiener (1948/1994) understands that the *synapse* is a "mechanism for determining whether a certain combination of outputs from other selected elements will or will not act as an adequate stimulus for the discharge of the next element, and must have its precise analogue in the computing machine" (p. 14).

Nonetheless, while cybernetics adopts a practice where these concepts were verified in the physical environment, through equipment and machines acting intelligently, the field of AI prefers to assume an abstract approach, where simulation based on the manipulation of symbols allowed by computers would already suffice to demonstrate intelligent processes (Johnston, 2008). John Johnston (2008) cites as emblematic that the work of von Neumann—who participated in Macy's lectures—was of fundamental importance to develop computers capable of storing programs instead of being mere powerful calculators (p. 59). Even so, broadly, cyberneticists did not keep up with this paradigm shift and remained tied to the physical machine (hardware bias, embodied), while primitive AI relied on the universal symbol processor (software bias, disembodied; p. 60). Leading AI Researchers Stuart J. Russell and Peter Norvig (2010) also add that "the answer [for such segregation] lies in the close coupling between the mathematical techniques that were familiar to the participants and the corresponding sets of problems that were encompassed in each world view" (p. 15).

In addition to von Neumann, other cybernetics scientists have made contributions that, to some degree, have supported AI advances. For example, it is possible to refer to the aforesaid "conversation theory" by Pask (1976), investigations about neural networks by von Foerster (1967/2003a) in the article "Computation in Neural Nets," among others. However, as previously mentioned, cybernetics and AI have built different fields, and in recent decades AI has had more expressive assimilation both in academia and society (Brites, 2018). Furthermore, these fields may be related in specific contexts, since their respective particularities are respected. For instance, in the 1970s, the *Generator* was an architectural project that managed to combine the cybernetic systemic logic and the insertion of AI programs.

The *Generator* project appeared in 1976 from an order placed by Gilman Paper Company in Florida (US). Cedric Price sought to develop a polyvalent orthogonal module to host cultural events, company activities, and artistic residencies (*Generator - Cedric Price Fonds*, n.d.). Such module—unbuilt—would be highly interactive and reconfigurable. Space transformations could be motivated by the users' needs and desires, or the initiative could also come from the built environment, aiming to stimulate the inhabitant.

In 1978, Price invited Cyberneticists John and Julia Frazer to join the *Generator* project team (Furtado, 2008, p. 57). The research in software development carried out by the Frazers and the expertise in cybernetics of both the Frazers and Price foster the emergence of an architectural project where cybernetics and AI approach work together. Furtado highlights the project "as a reconfigurable, modular complex [which] made possible its absorption within the technological framework of computation and artificial intelligence and, through the application of the Frazers' research, the project ended up being acknowledged as the first intelligent[19] building" (p. 56).

Some experimental projects from the early 2000s, such as MIT's *House_n* Project (Yiannoudes, 2016), *ADA* (Bullivant, 2005a), *Media House* (Bullivant, 2005b), among others, to some degree, explore cybernetics and AI jointly, seeking reference in the apparatus and potential of each area (Brites, 2018). It is reasonable to recognize that such projects continue a particular "tradition," formed by Pask's experiments and Price's projects, previously mentioned, and they can be linked to a radical pedagogy in architecture,[20] as defends Beatriz Colomina (2016).

Perceiving architecture as a control and interaction system, where even more specific subsystems can be designed, is a way to achieve a human-centered approach. In this context, it is possible to glimpse advances regarding contemporary demands, such as the issue of population aging, for example. As seen earlier, the cybernetic theory has provided essential concepts and experiences for architecture. On the other hand, AI can act by providing mathematical models and methods to help in this quest.

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[19] In this work, the term "intelligent architecture" is not used frequently because there is a lack of rigor around the term. Generally, the media and marketing in general—and even some publications in the area—use the term in a generic way, which trivializes it.

[20] In this research, the type of architectural work developed at the *Robot House*—and listed in the book *Robot House: Instrumentation, representation, fabrication* (Testa, 2017)—can be understood as possible heirs more contemporary of the aforementioned cybernetic tradition. In this context, these works, and the others discussed in the paragraph, are perceived as examples of disruptive architectural work in the sense delimited by Colomina (2016). Architect Peter Testa (2017) highlights part of these relationships and inserts the issue of AI when he states that: "With first-hand knowledge of technologies from artificial intelligence (AI) and machine vision (MV) that are coming to dominate the cultural landscape, projects emerging from Robot House's experimentation can be redeployed and form the basis for alternative design practices" (p. 21).

1.3.4 Artificial Intelligence

Since its emergence, artificial intelligence has been a fertile field for developments and evolution, but it has also allowed exaggerated promises and excess of optimism (Coelho, 1996; Russell & Norvig, 2010; Vignaux, 1991). For others, it is a source of skepticism and discredit (Coelho, 1996) or arouses environmental, ethical, and social concerns (Crawford, 2021). This research assumes that *AI* is a branch of computer science and, as such, it is based on mathematical logic creating algorithms that seek solutions to problems and situations that generally demand some intelligence to be fulfilled (Brooks, 1991; Oliveira, 2017).

In this context, it is relevant to understand that *algorithms* are a sequence of very detailed steps capable of processing data and, thus, seeking to achieve specific results (Oliveira, 2017, p. 6). Its origin and applications were developed in mathematics long before the emergence of modern computers. Russell and Norvig (2010) see in Aristotle[21] (384–322 B.C.E.) the first record of an algorithm (implemented 2,300 years later by Newell and Simon) in an evolutionary process that also includes Euclid (300 B.C.E.), Al-Khowarazmi (a ninth-century Persian mathematician who originated the term), and many other prominent names in the history of mathematics (p. 8). For Vignaux (1991, p. 15), records of "intelligent machines" are evident already in Iliad by Homer (928–898 B.C.E.).

Some authors, such as Dreyfus (cited by Coelho, 1996), in a broad historical view, point to the emergence of AI principles with Socrates (469/470–399 B.C.E.) and Plato (428/427–348/347 B.C.E.). Around 450 B.C.E. Socrates sought to develop irrefutable reasoning processes using syllogisms (Russell & Norvig, 2010, p. 4), establishing a kind of moral norm. In continuity, Plato tried to generalize such norm through an

[21] Here, it is possible to observe the algorithmic character proposed by Aristotle in *Nicomachean Ethics* (as cited in Russell & Norvig, 2010): "We deliberate not about ends, but about means. For a doctor does not deliberate whether he shall heal, nor an orator whether he shall persuade, . . . They assume the end and consider how and by what means it is attained, and if it seems easily and best produced thereby; while if it is achieved by one means only they consider how it will be achieved by this and by what means this will be achieved, till they come to the first cause, . . . and what is last in the order of analysis seems to be first in the order of becoming. And if we come on an impossibility, we give up the search, e.g., if we need money and this cannot be got; but if a thing appears possible we try to do it." (p. 7)

epistemological bias where all knowledge could be converted into normative definitions so that they could be applied as a set of rules (Dreyfus, as cited in Coelho, 1996, p. 44). Some researchers[22] see the dualistic Cartesian logic of understanding the truth through mathematics, proposed by René Descartes[23] (1596–1650) and presented in *A discourse on the method of correctly conducting one's reason and seeking truth in the sciences* (1637/2006[24]), as part of the philosophical foundation of AI:

> And indeed, I venture to claim that the scrupulous observance of the few precepts I had chosen gave me such ease in unravelling all the questions covered by these two branches of knowledge that in the two or three months I spent investigating them, having begun with the simplest and most general (every truth that I discovered being a rule that I used afterwards to find others), not only did I solve some which I had earlier judged very difficult, but it also seemed to me, towards the end of this period, that I was able to determine, even in respect of those questions which I had not solved, by what means and to what extent it was possible to solve them. In claiming this I will appear perhaps less conceited to you if you consider that, as there is only one truth of any one thing, whoever finds it knows as much as can be known about it, and that, for example, a child trained in arithmetic who does a sum according to the rules can be quite certain of having discovered everything the human mind can find out about the sum in question. In short, the method that teaches one to follow the correct order and to enumerate all the factors of the object under examination, contains everything that confers certainty on arithmetical rules. (Descartes, 1637/2006, p. 19)

In the reference textbook *Artificial Intelligence: A Modern Approach*, Russell and Norvig (2010) indicate several areas that, in one way or another, have contributed to the formation of AI, notably philosophy, mathematics, economics, cybernetics, neuroscience, psychology, computer engineering, and linguistics. In this immense universe, authors highlight some personalities who developed basic concepts for AI, such as Socrates, Plato, Descartes, Francis Bacon (1561–1626), George Boole (1815–1864), Gerolamo Cardano (1501–1576), Blaise Pascal (1623–1662), Thomas

[22] Russell and Norvig (2010, p. 1041), and even Friedberg (2006, pp. 53–54), in her book *The Virtual Window: From Alberti to Microsoft* (in another context), makes some mentions in this sense, relating René Descartes to AI and the Turing Test (see footnote 27).

[23] Additionally, Vignaux (1991, p. 15) lists the "machine animal" speculated by Descartes as an example of human ambition for artificial intelligence.

[24] This book was originally published in French, in 1637, under the title *Le Discours de la Méthode* (René Descartes even mentions the reason for using vulgar language, and not Latin). The version used here is translated into English and was published in 2006.

Bayes (1702–1761), John Watson (1878–1958), and Wiener, among many others (pp. 5–16).

Like Cybernetics, AI emerged in the post-World War II period in the US, and its inaugural event was the seminar at Dartmouth College in 1956 (Vignaux, 1991, pp. 23–24). However, according Russell and Norvig (2010), before that, it was already possible to report some works that are now recognized as AI. For example, in 1943, Warren McCulloch (1898–1969) and Walter Pitts (1923–1969) proposed a model of artificial neurons. In 1947 Alan Turing (1912–1954) was already lecturing on the subject in London, and, in 1950, he released his emblematic article "Computing Machinery and Intelligence," addressing the famous "imitation game" (also known as the Turing Test), notions about genetic algorithms, machine learning (ML), and reinforcement learning. Also, in 1950, Marvin Minsky[25] (1927–2016) and Dean Edmonds—then students at Harvard—built the first neural network computer (Russell & Norvig, 2010, pp. 16–17).

The seminar held at Dartmouth College in the summer of 1956 is regarded as the event that marked the emergence of AI (Coelho, 1996; Crawford, 2021; Oliveira, 2017; Russell & Norvig, 2010; Vignaux, 1991). According to Russell and Norvig (2010), John McCarthy[26] (1927–2011) sought the support of Minsky, Claude Shannon (1916–2001), and Nathaniel Rochester (1919–2001) to gather a select group of researchers interested in neural networks, automata theory, and the study of intelligence. Consequently, Trenchard More (Princeton), Arthur Samuel (1901–1990; IBM), Ray Solomonoff (1926–2009), Oliver Selfridge (1926–2008; both from MIT), Allen Newell (1927–1992), and Herbert Simon (1916–2001; both from Carnegie Tech) were added to this effort, totaling ten participants (p. 17).

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[25] Russell and Norvig (2010) report that Minsky's Ph.D. committee at Princeton was skeptical about works of this nature and questioned whether the topic—universal computing in neural networks—could be classified as a mathematics work: "But von Neumann reportedly said, 'If it isn't now, it will be someday.' Minsky was later to prove influential theorems showing the limitations of neural network research" (p. 17).

[26] McCarthy, in 1958, developed the high-level language Lisp (List Processing), which established itself as the leading AI programming language until the late 1980s (Russell & Norvig, 2010, p. 19).

The seminar did not yield any significant novelty, but it brought these researchers together around common goals, and "it did introduce all the major figures to each other" (Russell & Norvig, 2010, p. 18). The Computer Research Arlindo Oliveira (2017) reports that some of the participants became leaders in this field of research during the following decades, highlighting Minsky, Simon, McCarthy, and Newell. Another result of the event was the beginning of the dissemination of AI in the academy, and the creation of AI laboratories in renowned institutions, such as MIT, Berkeley, and Stanford, for instance (p. 79).

Attempting to define AI is not a simple task, not least because the concept of intelligence is—itself—complex (Oliveira, 2017, p. 88). However, it did not prevent many definitions from being placed. For example, Helder Coelho (1996), in the book *Sonho e Razão: Ao Lado do Artificial*, defines *AI* as the search for modeling the intelligent behavior of living beings through computational instruments (p. 34). In another passage, the author takes up the question again, stating that *classical AI* seeks to develop systems capable of performing tasks that require human intelligence to be solved, based on the general hypothesis that the human brain operates in a way comparable to computation, being therefore understood by mathematical logic (p. 146).

Russell and Norvig (2010) identify two dominant approaches concerning the definition of AI. First, one that seeks to build computer solutions based on the principle of rationality, therefore "a system is rational if it does the 'right thing,' given what it knows" (p. 1). Second, another that has human intelligence as its target and model. In the latter, the influence of the Turing Test (Turing, 1950) is reputable. This bias has led to the growth of significant branches of AI (Russell & Norvig, 2010, pp. 2–3); however, this anthropocentric search also brought demands and expectations that were difficult for AI to meet (Oliveira, 2017, p. 90).

The Turing Test, developed by Turing in 1950, "was designed to provide a satisfactory operational definition of intelligence" (Russell & Norvig, 2010, p. 2). The test—or game—briefly proposes a dynamic of written questions and answers where the computer passes the test if it manages to deceive the human interrogator[27] (Turing, 1950, p. 433). This test remains an unsurpassed challenge for AI; nevertheless, developers have been producing algorithms that increasingly approach this goal (Oliveira, 2017). It is also worth noting that the test has not been a goal pursued by AI as it was in its first decades. In any case, the Turing Test continues to be significant, either for its role in AI history or for the intellectual and philosophical questions it raises (Oliveira, 2017; Russell & Norvig, 2010).

Other challenges, chess game being a symbolic example,[28] were also relevant in the inceptive development of AI and have already been overcome (Oliveira, 2017, p. 89). These historically posed challenges helped to develop AI subfields. Russell and Norvig (2010) point out that challenges such as the Turing Test, for instance, have led to the flourishing of natural language processing (NLP), knowledge representation, automated reasoning, machine learning, computer vision, and robotics.

The subfields of AI are diverse and can act together, where accomplishments in one area may lead to new solutions in others. The delimitation of its subfields varies, depending on the author consulted. In addition to those already mentioned, it is possible to include games (Chess, IBM's *Deep Blue*, and others), expert systems, case-based reasoning (CBR), intelligent tutoring systems (ITS), and diagnosis, among others. The applications

[27] In this sense, it is curious to note that René Descartes, in 1637, had already had concerns that could be compared with the Turing Test (related to footnote 22): "At this point I had dwelt on this issue to show that if there were such machines having the organs and outward shape of a monkey or any other irrational animal, we would have no means of knowing that they were not of exactly the same nature as these animals, whereas, if any such machines resembled us in body and imitated our actions insofar as this was practically possible, we should still have two very certain means of recognizing that they were not, for all that, real human beings The first is that they would never be able to use words or other signs by composing them as we do to declare our thoughts to others. For we can well conceive of a machine made in such a way that it emits words, and even utters them about bodily actions which bring about some corresponding change in its organs (if, for example, we touch it on a given spot, it will ask what we want of it; or if we touch it somewhere else, it will cry out that we are hurting it, and so on); but it is not conceivable that it should put these words in different orders to correspond to the meaning of things said in its presence, as even the most dull-witted of men can do. And the second means is that, although such machines might do many things as well or even better than any of us, they would inevitably fail to do some others, by which we would discover that they did not act consciously, but only because their organs were disposed in a certain way. For, whereas reason is a universal instrument which can operate in all sorts of situations, their organs have to have a particular disposition for each particular action, from which it follows that it is practically impossible for there to be enough different organs in a machine to cause it to act in all of life's occurrences in the same way that our reason causes us to act." (Descartes, 1637/2006, pp. 49–50)

[28] The computer principles to structure a computational method for playing chess date from 1949 and were developed by Shannon (Vignaux, 1991, p. 16).

developed in the subfields are the *mold layers* of AI, while the fundamental principles make up its *hardcore* of AI (Coelho, 1996).

Oliveira (2017) remarks that, as relevant as subfields AI are, “machine learning is central to all activities requiring intelligence and is concerned with the ability of machines to learn from experience—the most substantial ability that a system must possess in order to exhibit intelligent behavior” (p. 95). He exemplifies stating that other relevant subfields, such as natural language processing, planning, computer vision, and robotics have significantly benefited from the methods and techniques developed by researchers in machine learning (which it will be discussed in “4.3.1 Machine Learning”).

Philosophically approaching, AI can still be classified into weak AI and strong AI. In the *strong AI* hypothesis, developers quest to replicate human intelligence, and computational processes must support explanations of cognitive functions. Otherwise, for the *weak AI* hypothesis, in the best-case scenario, human intelligence can only be simulated, and the general objective is to create machines capable of displaying intelligent behavior (Coelho, 1996, pp. 57–58; Russell & Norvig, 2010, p. 1020). Most AI developments are framed under the weak AI hypothesis.

AI evolution is not linear, going through periods of lesser prominence (known as the “*AI winter*”), with frustrations caused mainly by exacerbated expectations about natural language processing systems between the mid-1970s and the beginning of the 1980s. So, in the mid-1980s, expert systems were developed, which motivated the industry’s growing (economic) interest in AI. Such a move generated a new wave of euphoria, leading the Japanese government (among others) to invest massive resources in the “Fifth Generation” project, the subsequent failure leading to a new lowering of AI in the early 1990s. However, this process was soon reversed with internet massification and the wide use of AI algorithms within the online environment (Russell & Norvig, 2010).

From recent decades to the present, AI advances have penetrated the most diverse segments of society; its techniques are ubiquitous, and new applications are constantly emerging (Oliveira, 2017, p. 89). As a result, many promises of revolutions with practical implications to everyday life, medicine, management of cities, and many other possibilities are constantly registered (Russell & Norvig, 2010, pp. 28–29). Nonetheless, using various AI systems on a global scale, most of the time managed by private companies, having private interests, discussions about the ethical, social and environmental implications of AI are beginning to gain strength.

AI Researcher Kate Crawford (2021) addresses problematic points around AI, among them: the demand for environmental resources by the computing industry (especially rare ores); workforce exploitation, showing that nowadays AI still demands a large human workload in data centers; ethical questions about the large volume of personal data, without precise regulation on data protection and privacy, and how dangerous an improper manipulation of this data can be (themes also addressed by Harari, 2014/2020; 2018); the reproduction of discriminatory patterns by recognition and classification algorithms (mainly racial and gender discrimination). Crawford (2021) still places the origin of AI in the military context, with possible implications for individual liberties, permanent surveillance, and the strengthening of nationalist agendas. Many of these problematic points are not limited to AI, Historian Margaret O'Mara (2021) identifies a prevalence of gender and race inequality, military interests, and the preponderance of large monopolies, underlying the development of computing itself.

Nevertheless, much of the criticism is rather related to human management and human motivations leading to inadequate use of AI than about the technology itself. Accordingly, without having a naive view or a belief that every technological novelty should be necessarily positive, this research works with the possibility of beneficially using AI methods, including machine learning and its contributions to NLP, besides computer vision, as relevant interaction tools between humans and machines (as it will be addressed in Chapter 4).

1.4 Conclusion

This Chapter presents a large set of structuring concepts about domesticity, cybernetics, and AI. The narrative built around these topics intends to present relevant personalities, developments, and critical points, mediated by a concise historical framework. In each area, the research aims to understand what has been consolidated and what has emerged in contemporaneity in order to envision possible ways of interrelating them.

In “Domesticity” (1.2), the human domestication of space is analyzed, particularly emphasizing the transformations perceived throughout the eighteenth, nineteenth, and twentieth centuries. Such analysis pursues to apprehend how social, political, and economic changes have shaped the production of domestic space in Western culture. These alterations had significant implications for the emergence of other ways of living perceived more clearly in contemporary times. In this context, population aging deserves attention, as demonstrated by the data presented, regarding the Portuguese situation and the city of Lisbon. This phenomenon becomes an even more relevant issue for architecture since the desire to age at home and within their community (AiP) is expressed by most people.

In “Cybernetics and AI” (1.3), it was discussed how the growing mechanization of society (derived from the industrial revolution) made new fields of research necessary, such as cybernetics and its theory of control and communication. Furthermore, cybernetics emerged in the post-World War II context, when many scientists from different areas had worked together during that conflict. This fact fostered a strong interdisciplinarity in the cybernetic paradigm. Such interdisciplinarity enabled to open space to develop architecture in conjunction with cybernetic work. The pioneering works became grounds for many later projects, where a systemic, adaptable, and interactive approach to architecture could arise. Finally, AI emergence and improvement, as well as some questions surrounding its definition and objectives regarding the reproduction of intelligence are addressed.

The interaction among these three independent topics—domesticity, cybernetics, and AI—allowed for this work to glimpse points of approximation and complementarity. Thinking about architecture based on cybernetic principles and the possibility of using part of the AI apparatus as a method of interaction unfolds a range of possibilities for action in the face of some contemporary domestic challenges. For example, attempting to respond to some needs arising from the desire to remain in their own homes by older adults (AiP). Adjacent to this, it is reasonable to believe that part of the issues discussed here also help to substantiate the digital window concept that will be elaborated upon in the following chapter and to which the questions raised here remain linked.

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Digital Window Framework

[chapter]

2

Digital Window Framework

This chapter starts by investigating the concepts of prosthesis and materiality in the face of the blurring of dichotomies observed in contemporaneity. Based on this theoretical framework, the research proposes the digital window concept. As follows, it presents works that relate to this concept in one way or another. Literature review is the primary methodological tool in this chapter; however, it also uses unsystematic observation, interview, and in loco visit to show some related works. After establishing this theoretical framework and recognizing the concept of digital window in previous works, it becomes possible to envision its realization.

2.1 Introduction

In addition to the subjects already examined in Chapter 1, proposing the digital window concept demands a more specific look at the weakening of dualities observed in contemporaneity. Several authors have sensed it in the field of architecture. This blurring of dichotomies once seen as clear emerges from an intensification in transformations affecting the relationships among information, space, and body, especially in the last century (and continue to intensify). Accordingly, concepts such as prosthesis and materiality take on new contours, resulting from society's growing complexity.

In this theoretical framework proposed, the concept of "virtual window," defended by Anne Friedberg (2006), assumes considerable relevance. The author follows from the window metaphor by Leon Battista Alberti, in Renaissance painting, through the emergence of photography, cinema, television, computer, and internet to argue that the windows supporting these varied media are also architectural elements, comparable, in a certain sense, to the architectural window.

Based on Friedberg's metaphor (2006), the research proposes a variation of the concept of the virtual window, here identified as "digital window," where the body can experience new ways of combining architectural space and digital information. Therefore, this chapter conceptualizes a new metaphorical architectural element: the digital window. Then, it lists a set of works that, to some extent, anticipate or relate to the concept proposed.

Literature review (Wang & Groat, 2013, pp. 142–143) remains the primary methodological basis of the chapter; however, the search for information about related works (Princeton, 2019) required to incorporate other methods into the research, such as unsystematic observation (Marconi & Lakatos, 1985/2002, pp. 89–90), focused interview (p. 94), and in loco visit (p. 63). Hence, based on a set of organized information, this chapter continuity is structured as follows:

a) "Like a Second Sort of Body" (2.2): raises the issue of weakening some dichotomies such as natural and artificial, inside and outside, public and private, among others. The intensified perception of this phenomenon in contemporary times leads to studying the concept of prosthesis and materiality, from an architectural point of view.

b) "Digital Window" (2.3): initially seeks to outline a brief definition and historical understanding about the evolution of the window (and of glass). Next, the virtual window established by Friedberg (2006) is introduced, besides implications related to the concept of virtuality and the metaphorical aspect of the proposal. Upon these questions, the conceptual proposition of the digital window is put forward.

c) "Related Works" (2.4): presents architectural and cinematographic works that anticipate aspects regarding the digital window. While the architectural works have a more experimental approach, the cinematographic works are affiliated with the tradition of science fiction (sci-fi). This set of works is expected to strengthen the understanding of the digital window concept.

Thus, the digital window is established as a metaphor for an architectural element, which allows interpenetration of binary information and (domestic) space, configuring a prosthesis available to the inhabitant and challenging the traditional concept of materiality. Therefore, while Chapter 1 delimited the theoretical framework and more general concepts, Chapter 2 outlines the most intrinsic concepts, the conceptual definition of the digital window, and presents related works in order to support the next steps of the research.

2.2 Like a Second Sort of Body

2.2.1 Blurring

Contemporaneity has witnessed the blurring of many dichotomies that, as such, were previously seen as clearly distinct (Colomina, 1994; Diller & Scofidio, 1994; Furtado & Moreira, 2001, p. 96; Picon, 2003, p. 108; Spiller, 2006, p. 88; Teyssot, 1994, p. 20, 2005, p. 78; Tramontano, 1998; Vidler, 1992, p. 147; Wigley, 1991, p. 8). This phenomenon is motivated, among other factors, by the increasing mechanization verified in the twentieth century, with significant penetration into the domestic space (Vidler, 1992, p. 156). Moreover, this movement has been intensifying even more in contemporary times due to the proliferation of digital technologies, as the Architect and Theorist Georges Teyssot (2005) indicates when he states that "traditional and fallacious oppositions such as interior/exterior, public/private, organ/function, because with the introduction of digital technologies those distinctions have been blurred" (p. 81).

An extensive set of dualities has had its borders blurred vis-à-vis the transformations since last century. For example, Marshall McLuhan (1911–1980), in *Understanding Media: The Extensions of Man* (1964/1994), underlines that the popularization of electrical energy in the twentieth century brought significant changes to housing and architecture, suppressing the boundaries between day and night, internal and external, and even between terrestrial and underground, regarding the elevators (pp. 126–127). In turn, Colomina (1994) perceives technological changes and the mass media "as a mechanism that disrupts the older boundaries between inside and outside, public and private, night and day, depth and surface, here and there, street and interior, and so on" (p. 12). While Teyssot (2005) provides an even broader set of examples relating dichotomous relationships affected by what the author calls cyborg culture: "mind/body, animal/human, public/private, nature/culture, male/female, primitive/civilised, virtual/real" (p. 78).

This phenomenon is perceived in different ways, in different contexts. For example, in the field of arts, the Artists and Architects Elizabeth Diller and Ricardo Scofidio (1994) identify evidence supporting this tendency in the work of Marcel Duchamp (1887–1968), when they state that "Duchamp used hinging as a reprogramming device in his Readymades" (p. 115). As the authors discern, particular works by Duchamp subvert the utilitarian function—and the physical position—of objects, converting them into art objects (utilitarian versus artistic character); in other productions, the artist uses, for instance, androgyny, as a hinge to blur the distinction between gender roles (female versus male; Diller & Scofidio, 1994).

From the bias of prostheses and the cyborg culture mentioned earlier (which will be better addressed in the following item, "2.2.2 Prosthesis"), Architect Mark Wigley (1991, 2010) believes that body alteration through prosthesis leads to redefining its limits and the blurring of the boundary between the natural and the artificial. Complementarily, for the Architect and Historian Anthony Vidler (1992), the relationship between organic and inorganic is "blurred by cybernetic and bio-technologies" (p. 147).

The spatial relationship amid what is considered close or distant has also undergone a strong change with the advancement of digital technologies. Nevertheless, well before that, this tendency had been already noticed, as Le Corbusier (1887–1965) attested with his concept of *interpenetration*, consisting of the ability offered by mechanization to connect distant spaces in an increasingly shorter time interval (Le Corbusier, as cited in Colomina, 1994). In the approach proposed by Le Corbusier, such a movement began with the locomotive and was successively intensified by new technological advances, such as the telegraph, radio, telephone, airplane, and—the then-new—television. For the architect, mechanization overcame distances, enabling coexistence (interpenetration) between different locations, "hastening interpenetration, the railway, [and] the telephone unceasingly run the country into the city, the city into the country…" (Le Corbusier, as cited in Colomina, 1994, p. 332).

Colomina (1994), in her book *Privacy and Publicity: Modern Architecture as Mass Media*[29] investigates, through the analysis of works by

[29] This is the same book where the author retrieves the concept put forward by Le Corbusier about "interpenetration," mentioned in the previous paragraph.

architects Adolf Loos (1870–1933) and Le Corbusier, the impact of mass media on the relationship between public and private in modern architecture. For the author, “with modernity there is a shift in these relationships, a displacement of the traditional sense of an inside, an enclosed space, established in clear opposition to an outside. All boundaries are now shifting” (p. 12). In this context, modernist picture windows are examples of devices that operate this weakening of dualities concerning the public and the private. This element, recurrently used by Le Corbusier, converts the house interior into a publicized image, while the exterior is visually integrated with the interior of the house, functioning as a media screen:

> For Le Corbusier the interior no longer needs to be defined as a system of defense from the exterior. To say that “the exterior is always an interior” means that the interior is not simply the bounded territory defined by its opposition to the exterior. The exterior is “inscribed” in the dwelling. The window in the age of mass communication provides us with one more flat image. The window is a screen. (Colomina, 1994, p. 334)

For Vidler (1992), the trend toward weakening the public and private opposition has intensified even more in contemporaneity, where “the public realm of the cybernetic—is now brought home” (p. 163). The author realizes that “private space is revealed as infinitely public, private rituals publicized to their subjects and these in turn connected to the public matrix”[30] (p. 163). Critical points may emerge from this situation that Vidler calls “posttechnological domesticity” (p. 163), where the house is converted into an agent of control, a role previously played almost exclusively by public surveillance.[31] Colomina, in her books *Domesticity at War* (2006) and *X-Ray Architecture* (2019), reinforces this view of control that accompanies the publicity of domestic space. In the author’s words, “glass walls, like x-rays, are instruments of control. From the outside, the glass exposes the house to the public, as if guaranteeing conformity to the community” (Colomina, 2006, p. 153).

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[30] It is worth mentioning that Vidler makes this statement in the article “Homes for Cyborgs” published in his book *The Architectural Uncanny: Essays in the Modern Unhomely*, in 1992, before the emergence of social networks where this behavior of private exposure in (digital) public space has been dramatically intensified.

[31] The formatting of public and private roles in recent centuries was briefly mentioned in “1.2.1 A Brief Historical and Conceptual Contextualization of Domesticity.”

Teyssot (1994, 2005) brings up the issue of disembodiment by stating that “with the increasing use of machines and of transportation and communication technologies, and the spread of ever-more mediatized operations, we are arriving at, some say, a disembodied style of life” (1994, p. 10). For the author, new architectural possibilities may come from this disembodiment and from a new way of thinking about the process of integrating the body with the machine, far from the mechanistic tradition based on Cartesian dualism (1994, p. 16). In this sense, the phenomenon of disembodiment can be understood as a stage of blurring the Cartesian duality between body and mind.[32]

In a scenario with blurred dichotomies, the consequences can be diverse, both problematic, as pointed out by Vidler (1992) and Colomina (2006, 2019) regarding domestic surveillance, and opportune as indicated by Teyssot (1994, 2005) on the possibilities opened up by the understanding of the extended body in contemporary times. So, investigating how these processes develop, including the concept of prosthesis and, consequently, the cyborg culture, becomes a relevant task in architecture.

2.2.2 Prosthesis

Prostheses are technological complements that aim to fill a lack, loss of ability, or even endow an organism with a new capability (Wigley, 1991). For Wigley (2010), the prosthetic relationship precisely happens when the biological entity incorporates a technological extension, in an evolution process of both the species and its environment (p. 53). This relationship blurs the boundaries between artificial and natural since both parts change themselves in this process.

In his article “Prosthetic Theory: The Disciplining of Architecture,” Wigley (1991) reports that prostheses originated in a medical-military context, and mentions, as an example, the pioneering work of the Surgeon Ambroise Paré (1510–1590), still in the sixteenth century. Paré developed prostheses in order to replace body parts lost in war. According to the author,

[32] With immense philosophical implications, this duality was initially verified in the work of Descartes (1637/2006), *A Discourse on the Method of Correctly Conducting one’s Reason and Seeking Truth in the Sciences* (book mentioned in “1.3.4. Artificial Intelligence”).

weapons are also considered prostheses due to configuring attack and defense mechanisms and work as an extension of the body. Furthermore, it is curious to note that for this reason, in English, the word “arms” is used both to designate the human limb, as well as levers and weapons (pp. 22–23).

The etymology of the word “prosthetic” derives from “thesis,” which in its Greek origin is associated with the idea of “positioning,” “proposition,” “maintaining a position even in the face of attacks,” “taking a position” (Wigley, 1991, p. 9). For Wigley (1991, 2010), this fact highlights the intrinsically architectural nature of prostheses. Moreover, in a complementary relationship, it is possible to understand that architecture also has an intrinsically prosthetic nature (Krueger, 2006; Teyssot, 1994, 2005; Vidler, 1992; Wigley, 1991, 2010), like Le Corbusier had used to state (Colomina, 1994; Wigley, 1991).

Wigley (1991, 2010) also notices contributions from McLuhan and Le Corbusier in discerning the concept of prosthesis. For example, McLuhan acknowledged electronic evolution as an evident expansion of human capabilities (the computer electronic memory can be understood as the expansion of human memory,[33] for instance). At another point, McLuhan framed architecture as an extension of the human being, as well as the media (McLuhan, as cited in Teyssot, 2005, p. 80). On the other hand, Le Corbusier, from an architectural point of view, understood the artifice as a response to human needs, enabling to extend human capabilities through artificial limbs:

> We all need means of supplementing our natural capabilities, since nature is indifferent, inhuman (extra-human), and inclement; we are born naked and with insufficient armor. . . . The barrel of Diogenes, already a notable improvement on our natural protective organs (our skin and scalp), gave us the primordial cell of the house; filing cabinets and copy-letters make good the inadequacies of our memory; wardrobes and sideboards are the containers in which we put away the auxiliary limbs that guarantee us against cold or heat, hunger or thirst. . . . Our concern is with the mechanical system that surrounds us, which is no more than

[33] McLuhan (1964/1994) states, right in the introduction to *Understanding Media: The Extensions of Man*, that: “during the mechanical ages we had extended our bodies in space. Today, after more than a century of electric technology, we have extended our central nervous system itself in a global embrace, abolishing both space and time as far as our planet is concerned” (p. 3), also relevant to the subject addressed in footnote 66.

> an extension of our limbs; its elements, in fact, artificial limbs. (Le Corbusier, as cited in Wigley, 1991, p. 7)

Colomina (1994), about adopting the picture window in Le Corbusier's work, states that he understands the house as a vision device. The windows were, for the architect, comparable to the eyes, that is, a prosthesis capable of fulfilling functions compatible with human organs (pp. 7–8), "objets-membres-humains"[34] (Le Corbusier, as cited in Vidler, 1992, p. 156). In this context, it is relevant to consider that the Greek word "*organon*" refers both to the organs of the body and to mechanical equipment capable of exerting efforts; therefore, both the word "organ" and "machine" share a common origin (Teyssot, 1994, p. 16). For Wigley (1991), "the prosthesis reconstructs the body, transforming its limits, at once extending and convoluting its borders. The body itself becomes artifice" (p. 9).

Recognizing that the body becomes an artifice when it is integrated into a prosthesis leads to the introduction of the cyborg concept, belonging to the cybernetic paradigm, which confirms the issue of "blurring." As Teyssot (2005) states: "the cyborg has displaced the limit between organism and machine by coupling cybernetic devices with biological organism; it has blurred the distinction between animated and unanimated through the theory of the behaviour of homeostatic systems" (p. 79). The term "cyborg"[35] comes from a combination of the words "cybernetic" and "organism" and is inscribed, to some extent, in a long cultural tradition about hybrid beings, from the Greek Chimera (Teyssot, 2005, p. 79) to novels and science fiction about automata (Vidler, 1992, p. 157), resulting in many film adaptations on the theme, such as *Blade Runner*[36] (Scott, 1982) and *RoboCop* (Verhoeven, 1987), for instance (see *Figure 2.1*).

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[34] Vidler (1992), in his article "Homes for Cyborgs," uses the expression used by Le Corbusier "objets-membres-humains," (p. 156) literally and more than once, as a way of evidencing understanding (or position) of the French-Swiss architect on the concept of prosthetics in architecture.

[35] Teyssot (2005) informs that, "the terminology was proposed by two physicians, Manfred Clynes (engineer and neuropsychologist, who studied music, physics and mathematics), and Nathan S. Kline (psychiatrist), at the bio-cybernetics research laboratories at Rockland Psychiatric State Hospital in Orangeburg, New York, in a study related to astronautics for NASA during the 1960s." (p. 78)

[36] It is worth mentioning that the sequel to this movie, *Blade Runner 2049* (Villeneuve, 2017), is one of the works analyzed in "2.4 Related Works."

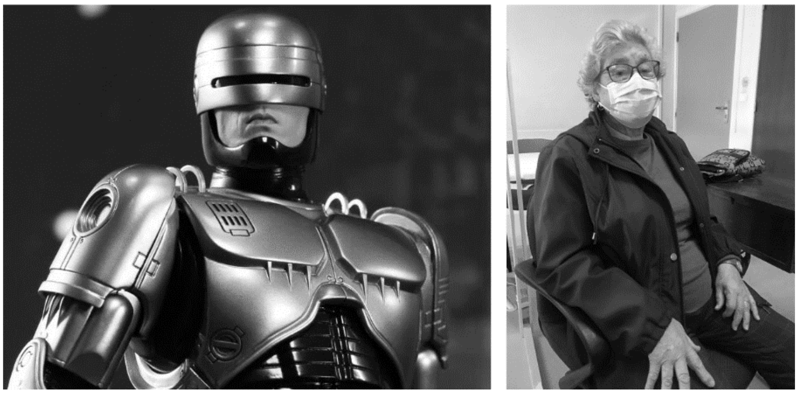

Figure 2.1 *On the left a cyborg imagined by sci-fi in 1987 (available at https://game-hall.com.br/novo-filme-de-robocop-e-confirmado-com-diretor-de-distrito-9/robocop-1/ accessed at 16/11/2021), and on the right a cyborg in 2022*

As Teyssot (2005) puts it, “like a cyborg, but without the excitement of science fiction, first the body is created, then it is plugged to every possible device, and at last it can be reconfigured” (p. 79). Architect and Theorist Antoine Picon (2003) understands that a cyborg relationship is established when the human comes into contact with the machine, and this encounter has the power to change world’s experience. It can be noted in the example of using the digital interaction prosthesis “mouse,” as reported by Wigley (2010). Or even, according to Picon (2003), in the relationship that is established when one uses a car (as will be discussed in “2.2.3 Materiality”).

Regarding the cyborg relationship established with the use of the mouse, Wigley (2010) perceives this example as a perfect integration between the body and the prosthesis. In this context, the body’s capabilities are extended since the device allows electrically impulsing the nervous system to be stimulated and identified by the electronic signals of the computer, combining both systems (p. 50). The author understands that “the daily dive into the computer is not a leap from analogue to digital or from real to simulation, but a choreographed blurring of the two, a smoothing over to activate a continuous interactive circuit” (p. 52). This connection, so important in the process of the domestication of computing, proves to be a case of successful assimilation since, during its use, the prosthesis tends to go unnoticed (pp. 52–53).

The process of “disappearance” of the prosthesis, according to Wigley (2010), attests to its perfect integration. This fact reinforces McLuhan’s argument that a prosthesis—successful—impacts the relationship with the human so profoundly that it is only noticed when it is no longer available or is superseded by another (McLuhan, as cited in Wigley, 2010, p. 53). Teyssot (1994) observes that the process of assimilation of a prosthesis corresponds to its “incorporation” and brings the Latin origin of the term “corpus,” which corresponds “to bring within a body” (p. 15), confirming the relationship between body and prosthesis. For Teyssot (1994), “incorporation is what enables us to acquire new abilities; these abilities can settle into fixed habits. As time passes, these repeated habits are definitively ‘incorporated’ and disappear from our view” (p. 15).

In the continuity of this prosthesis assimilation process, Teyssot (1994) identifies that a process of spatial incorporation of the prosthesis is also established (p. 15). Understanding this phenomenon is architecturally relevant and allows one to glimpse opportunities, as Architect Michael Wihart (2015) does when he states that “as corporeal capacities and sensitivities are projected outside the body the promises of humanisation shine onto architecture” (p. 160). However, the cyborg relationship between body and prosthesis is not always neutral or positive, demanding careful scrutiny to prevent a reversal of control roles (Vidler, 1992).

Vidler (1992) argues that just as prostheses are manipulated, they can also manipulate back (p. 158). The author cites the example of modernist prostheses that forced a pattern of postures and behaviors and others that sought to control the body in the logic of Taylorist production (p. 158). According to Vidler (1992), “the modernist prosthetic object was equally a master: the etiquette machines fabricated by Schreber for his children [...] as well as the taylorized furniture of the Gilbreths were all so many devices to control the body for its own good” (p. 158; see *Figure 2.2*). Teyssot (1994) regards these devices as problematic proposals that lead to disarticulation between systems (p. 15) and often seek to perpetuate limiting modernist standards and a hygienist view of society (p. 24), as briefly addressed in “1.2.1 A Brief Historical and Conceptual Contextualization of Domesticity.”

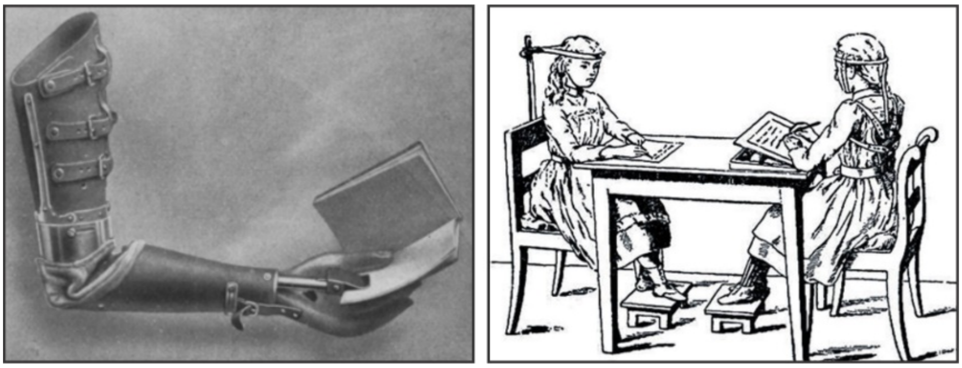

Figure 2.2 *On the left "Artificial intelligence? From Orthopadische Behandlung Kriegsuerwundeter, 1915" (Wigley, 1991, p. 7); and on the right "'Geradehalter,' a device to correct poor sitting posture, from Doctor Schreber's Kallipaedie" (Teyssot, 1994, p. 24)*

The perception of these critical points allows thinking architecture as a set of systems that must be articulated in the best possible way, always based upon the body and its needs. The objective is not to design a house for science fiction cyborgs but to conceive a space capable of housing a prosthetically expanded body (Teyssot, 1994, p. 16). According to Teyssot (1994), "the body is also the focal point of a transformation of architecture through a slow but potent process of domestication of space, which Siegfried Giedion was among the first to acknowledge in *Mechanization Takes Command*" (pp. 27–28). In the contemporary context of intensified mechanization and digitization of society:

> The urgent task architecture ought to assume, therefore, is that of defining and imagining an environment not just for "natural" bodies, but for bodies projected outside themselves, absent and ecstatic, by means of their technologically extended senses. Far from assimilating the tool with the body according to the mechanistic tradition of Cartesian dualism, we must conceive tools and instruments ***like a second sort of body*** [emphasis added], incorporated into and extending our corporal powers.[37] (Teyssot, 2005, p. 81)

Therefore, "like a second sort of body" (Teyssot, 2005, p. 81), architecture and, consequently, the house must be seen as a space sensitive to the body. A body enhanced by prostheses and altered by the changes felt in contemporary times. In this context, architecture is responsible for mediating diverse prosthetic relationships, grouping and regulating them according to the common objective of expanding the body's capabilities, or even,

[37] The same author uses a similar text on page 16 of "The Mutant Body of Architecture," introductory text to Elizabeth Diller and Ricardo Scofidio (1994) book *Flesh: Architectural Probes*. However, in this text, the final passage— "like a second sort of body, incorporated into and extending our corporal powers" (hence the title of this section)—is credited to philosophy professor Drew Leder in *The Absent Body*, 1990.

depending on the context, mitigating or canceling any loss or absence of abilities (due to the human aging process, for example).

In a broader approach, where prostheses are always architectural, and architecture is a type of prosthesis (Wigley, 1991, 2010), connecting body and machine gains relevance. This cyborg relationship is part of a hybrid "space" where many definitions are blurred (Teyssot, 1994, 2005), and the concept of materiality itself deserves an update. In this context, understanding space as an asset in the relationship between the body and the machine is one of the "urgent task[s] architecture ought to assume" (Teyssot, 2005, p. 81).

2.2.3 Materiality

Among the various apparent dualities that have been blurred in contemporary times, especially by digital technologies, the opposition of materiality and immateriality is particularly relevant to architecture. However, this is a longstanding issue; Friedberg (2006), for example, mentions that Siegfried Giedion pointed to a great dematerialization due to the extensive use of glass in the *Crystal Palace*.[38] For her, glass brings this paradoxical characteristic of being material, but which, because of transparency, suggests some immateriality, or at least a visual dematerialization (p. 117).

Friedberg (2006) addresses the issue of materiality arguing that "virtual images have a materiality and a reality but of a different kind, a second-order materiality, liminally immaterial" (p. 11). The difficulty in establishing a clear boundary between what is material and what is immaterial in contemporary times is also a research topic for Antoine Picon in his article "Towards a new Materiality?" (2003) and in the lecture "Architecture and Materiality in the Digital Age" (2016). Both works approach this issue from the perspective of architecture and architectural design.

For Picon (2016), digital information offers a new way of experiencing the world, which has implications for the perception of materiality.

[38] Gordon Pask (1969) refers to this same project as well as to the *Tropical House at Kew* and *Temple Meads*, as examples of an architecture that emerged quickly to meet new demands posed by technological advances during the Victorian era, those, in such a historical context, do not find critical support for their innovative nature in architecture (pp. 69–70).

Picon (2003) establishes a simple analogy between the experience of walking around the city and traveling in a car. According to the author, in both cases, contact with the world is established; nonetheless, each context offers different possibilities, which result in specific experiences. When the body was associated with a machine (*cyborg relationship*), the machine altered the experience (its speed, shape, and environment systems, among other issues). However, the materiality of the experience was not suppressed, only altered; in the author's words, "in brief, the automobile has not diminished our physical perception of the world. It has altered it. It has displaced the content and boundaries of materiality" (p. 108).

According to Picon (2003), this is because the experience of materiality, among others, is mediated by cultural constructions. In this context, technological culture significantly impacts how materiality is perceived in contemporary times (p. 107). Therefore, the author does not grasp a growing dematerialization sponsored by technology (or the computer); instead, technology alters events and the way how materiality can be experienced. As Picon (2003) states, "computer also alters our perception of objects; it extends the realm of our sensations" (p. 109).

Consequently, Picon (2016) understands that *materiality* is the relationship or sense one has with the matter, with the physical world. Besides, at the same time, the author (2003) states that technological culture has the power to change human spatial experience (p. 108). Accordingly, it is up to the discipline of architecture to structure how and to what extent technological culture can participate in the process of spatial and material perception. In this context, the author cites some sci-fi movies—including *Minority Report*[39] (Spielberg, 2002)—that illustrate, to some degree, this type of architectural possibility (Picon, 2003, p. 109).

In the same way that materiality can be perceived and experienced in a less literal way, not limited to the physicality of events; immateriality can also be (culturally) verified in apparently material contexts, as Colomina (1994) argues about Corbusian *villas*:

[39] This mention made by Picon (2003) is one of the reasons why this film is examined in "2.4 Related Works."

> The house is in the air. It has no front, no back, no side. The house can be in any place. It is immaterial. That is, the house is not simply constructed as a material object from which certain views then become possible. The house is no more than a series of views choreographed by the visitor, the way a filmmaker effects the montage of a film. (p. 312)

Besides the blurring of boundaries between material and immaterial, Teyssot (1994, p. 10) raises the matter of a growing disembodiment as transport and communication technologies advance (as mentioned). Rendering to the understanding of materiality proposed by Picon (2003, 2016), it is possible to notice that this is another trait of technological culture-shaping new forms of presence, allowing even the materiality of the body (disembodied) to be experienced in different ways.

These phenomena strain the relationships—body and machine, body and space, space and machine—toward hybridization of space (as presented in *Minority Report*, for instance), where the physical and the digital enable diverse possibilities of materiality. According to Picon (2003), "this hybridization is not yet fully there, but some features of the displacement of materiality can be already observed" (p. 109). The author also adds that the expanded perception of materiality, instead of posing a threat to architecture, leads to new opportunities and responsibilities (p. 111).

Hence, as previously mentioned—and this is a key idea in this research—architecture "must conceive tools and instruments like a second sort of body" (Teyssot, 2005, p. 81), considering that technological culture enables other experiences concerning materiality. In this way, the digital window emerges in a context where many dichotomies are blurred, the concepts of prosthesis and cyborg relationship foster the hybridization of the architectural space, and materiality has its concept expanded.

2.3 Digital Window

In order to introduce the concept of a digital window, it is first necessary to understand the window as an architectural element and apprehend, albeit briefly, aspects of its historical evolution: which is often confused with the historical evolution of glass. This path will aid to grasp the assimilation of this element into Western society. Culturally, such assimilation has allowed the establishment of metaphors that amplify and re-signify the architectural functions generally expected from this device in the so-called “Age of Windows.”[40]

A *window* is an architectural opening, an element primarily responsible for providing natural lighting and ventilation to indoor environments. Its dimensions, forms, and use are conditioned to many variables, from climatic conditions to stylistic issues (Neufert & Neufert, 1936/2012, p. 97). For some authors, modern architecture—and the various reasons that led to establish the movement —has highlighted the preponderance of a third function of the window: framing the view (Colomina, 1994; Friedberg, 2006). As Friedberg (2006) points out, “a brief history of fenestration will demonstrate how the window as an architectural opening for light and ventilation ceded its priorities to the modern function of the window: to frame a view” (p. 103).

When looking at the origin of the English word “window,” it is linked to the Old Norse *vindouga*, where *vindr* means “wind,” and *auga* refers to “eye” (Friedberg, 2006). Therefore, the word etymology already attests to its function of allowing ventilation of the eyes. In French, German, and Italian, the respective denominations “*fenêtre*,” “*fenster*,” and “*finestra*” derive from the Latin *fenestra* (p. 103), related to the idea of opening. In Portuguese, the term “*janela*” comes from *januella* (Latin), which is the diminutive of the word “*janua*,” used to designate “door,” that is, the windows would be a smaller version of the doors (Nascentes, 1966, p. 426). Thus, the

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[40] The term “Age of Windows” (also mentioned in footnote 42) comes from the sci-fi novel by H. G. Wells’s *The Shape of Things to Come*, adapted for movies in 1936 by William Cameron Menzies. In the movie, at a given moment in the imagined year 2036, it is mentioned that the “Age of Windows” lasted four centuries (Friedberg, 2006, p. 103; Menzies, 1936). This is one of the movies it will be studied in “2.4 Related Works.”

origins of names for this architectural element show both its primary functions and its complementarity to the door. About this set of openings, the Renaissance artist Alberti pragmatically distinguishes them, saying that "there are two types of opening, one for light and ventilation, and the other to allow man or object to enter or leave the building" (Alberti, 1435, as cited in Friedberg, 2006, p. 30).

The evolution of the window[41] has led to many variations, oftentimes being confused with the development and alternation of architectural styles (or as an outcome of these, among other factors) throughout the history of architecture. According to Friedberg (2006), there are already records of representation of windows from the ancient Egypt and Assyria. For the Romans, the window is no longer just a tiny opening for lighting and ventilation after the introduction of glazing (p. 103). Nevertheless, the popularization of glass in windows only occurred around the seventeenth century, according to Rybczynski (1986/1989, p. 47).

Friedberg (2006) discerns that glass plays a crucial role in improving windows, allowing lighting but not necessarily linked to ventilation; this is an important issue for the modernist picture window. The production of glass for windows, in general, demanded the improvement of techniques in order to achieve transparency and ideal flatness. The glass production process can be summarized melting, through exposition to high temperatures, and subsequent cooling of crystalline materials, such as oxides of sand (silica), soda, potash, and lime (p. 104).

Also, according to Friedberg (2006), the improvement of techniques enabled the creation of colored glass, widely used in the stained-glass windows of Gothic cathedrals during the Middle Age. Stained-glass windows work as illustrations that had the pedagogical function of assisting in the indoctrination of the faithful (p. 107). Later, throughout the sixteenth and

[41] As an example regarding the diversity of factors that led to transformations of the window, it is possible to mention the development of the guillotine-type window, developed in the Netherlands at the beginning of the seventeenth century (Rybczynski, 1986/1989). Houses were built on slender land, with small facades facing the public road and canal. As houses were structured on stilts and supported on each other, continuously, the facades allowed inserting a greater glazed area. However, for the sake of space utilization, the vertical movement of opening and closing, which characterizes guillotine windows, proved to be the most adequate. Also, according to Rybczynski (1986/1989), this model was quickly exported to France and England and later to all Europe (pp. 62–68).

seventeenth centuries, the evolution of techniques for developing mirrors deserves a highlight, which, in addition to raising several philosophical questions, can be compared to windows, as the author does when stating that “the mirrors also frame an empty pictorial space: the image inside each mirror is an image of the window” (Friedberg, 2006, p. 109). The emblematic *Galerie des Glaces* (completed in 1684) at the *Palace of Versailles* is an example of this interpretation (p. 109; see *Figure 2.3*).

Figure 2.3 *Galerie des Glaces (image by Thomas Garnier, available at https://www.facebook.com/chateauversailles/photos/la-galerie-des-glaces-de-nuit-the-hall-of-mirrors-by-night-epv-thomas-garnier/10156947740183674 accessed at 15/01/2022)*

In the late seventeenth century, the French developed an accurate glass polishing system, improving the production of glass plates[42] (Friedberg, 2006). Revolutionary works appeared during the nineteenth century, such as the aforementioned *Crystal Palace* (1851[43]), by Joseph Paxton (1803–1865), consisting basically of cast iron and transparent glass plates (Pask, 1969, p. 69). For Friedberg (2006) these works brough the viewer into a new visual

[42] Probably the improvement in glass production (Friedberg, 2006), associated with its popularization (Rybczynski, 1986/1989), were facts that made H. G. Wells determine the seventeenth century as the beginning of the “Age of Windows,” mentioned in the footnote 40.

[43] Coincidentally (or not) 1851 is the year that marks a change in property taxation in England, until then based on the number of windows, as Friedberg (2006) points out: “Between 1696 and 1851 property tax in England was assessed not by the square footage of property but by the number of windows, enforcing both the measure of glass as a taxable luxury and the number of windows as a measure of privilege. The British taxing of windows set the precedent for the French door and window tax between 1798 and 1917. Windows were a measure of property and wealth, indicating the privilege of those possessing a window view.” (p. 111)

system, the wall being visually suppressed and “the sense of a framed window as a perforation of the wall was lost” (p. 113).

Architecture has accommodated these evolutions—not always linearly—and developed diverse types of windows for specific purposes, like shop windows (Friedberg, 2006, p. 113). This type of window had its dimensions considerably increased during the nineteenth century, in some cases allowed by adding metallic structures to commercial buildings (Giedion, 1959). According to Giedion (1959), “it was from these store windows that we first learned how to use large glass areas in dwelling houses” (p. 193).

In the twentieth century, the window had already undergone a series of structural advances, allowing it to take over entire façades, as exploited by the Modern Movement in different ways. Friedberg (2006) cites a lecture given by Le Corbusier in 1929 where he demonstrated that architecture history could be seen through the history of the window (p. 104). Comparably, in 1938, Architect Lúcio Costa (1902–1998) proposed an illustrative panel regarding the historical evolution of Brazilian architecture (see *Figure 2.4*), which recorded the transformations of windows until arriving at the modern picture window (Costa, 1995).

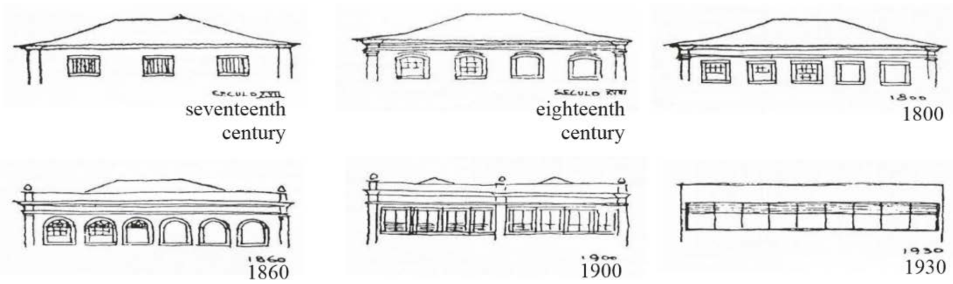

Figure 2.4 *Evolution of the window in Brazilian architecture, from the seventeenth century to the 1930s (Costa, 1995; edited)*

For Friedberg (2006) “as the window becomes the wall and the wall becomes a window, the wall also becomes a screen and the screen becomes a window” (p. 123). Accordingly, the author evidenced both new material relationships that the window assumed regarding the wall as its connection with the mass media (“screen”). This point is also defended by Colomina (1994), especially relating to Le Corbusier’s work.

According to Colomina (1994), Le Corbusier recognized the modern house as an image production system, “a mechanism of viewing” (p. 7). Bearing in mind the prosthetic approach established earlier (“2.2.2 Prosthesis”), the author records that Le Corbusier understood the window as an organ, and the architect literally used this word when referring to the window, stating that the window is the “most restricted organ of the house” (Le Corbusier, as cited in Colomina, 1994, p. 7). Hence, “the inhabitant is enveloped, wrapped, protected by the pictures” (p. 7), produced by the eyes of the house: the windows. Colomina (1994) points out this process as responsible for the landscape domestication, about which the author states that “it is this domestication of the view that makes the house a house” (p. 315).

Le Corbusier saw the window as a mechanism for lighting and framing the view, disregarding the issue of ventilation (Colomina, 1994, p. 324; Friedberg, 2006, p. 123). Complementarily, Colomina (1994) ponders that during the process of domestication of electrical energy, the idea that electricity could supply lighting and ventilation was disseminated, as suggested by the 1934 advertisement of “*La Compagnie parisienne de distribution d’électricité*” (p. 301; see *Figure 2.5*). In this way, the window would assume its primary modern vocation, delimiting the view and coordinating the visual relationship between the interior and the exterior (p. 301).

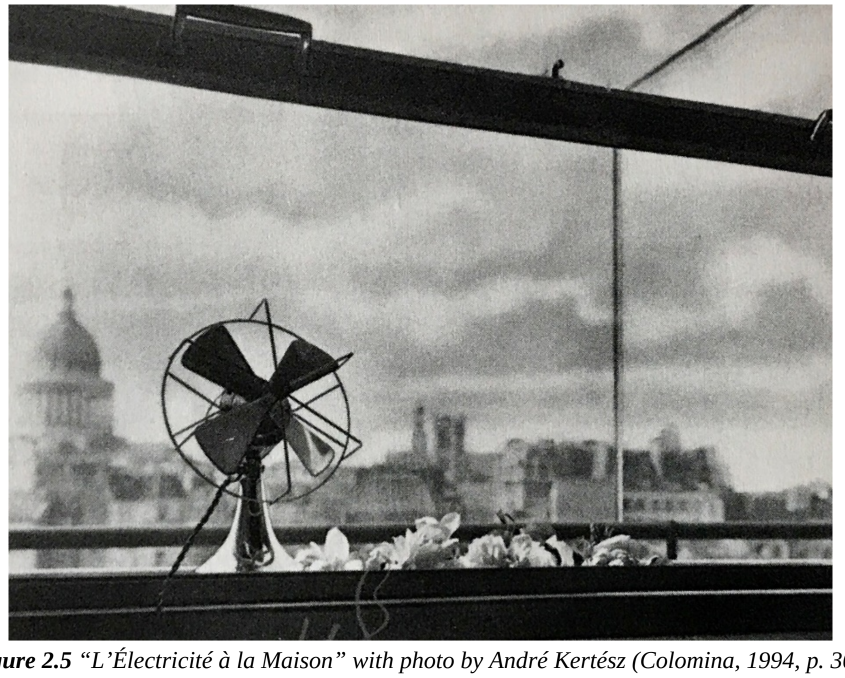

Figure 2.5 *“L’Électricité à la Maison” with photo by André Kertész (Colomina, 1994, p. 302)*

Le Corbusier’s project for Beistegui in 1932 is emblematic to understand the house as an image production system[44] and how electricity could allow new solutions that potentiated this objective (Colomina, 1994). Le Corbusier took advantage of the penthouse privileged location and designed electronic devices to generate frames (see *Figure 2.6*) of four Paris landmarks: the *Arc de Triomphe*, the *Eiffel Tower*, *Notre-Dame*, and *Sacré-Coeur* (p. 303). This project exemplifies Colomina’s (1994) claim that “the house is a frame for a view. The window is a gigantic screen” (p. 323).

Figure 2.6 *Electronic devices framing the view of Paris in Beistegui’s apartment (Mozzato, 2018)*

This paradigm shift about the role of windows reinforced by modernism is a relevant case that confirms the weakening of dualities, as previously mentioned (“2.2.1 Blurring”); the distinction between indoors and outdoors has been deeply shaken (Colomina, 1994; Friedberg, 2006; Vidler, 1992). The popularization of electricity use, the consequent mechanization of society, and the development of mass media and computing are some of the main factors that allowed the way of understanding windows to be expanded. In this context, and based initially on Alberti’s window metaphor, Friedberg (2006) proposes what she calls a virtual window at the very opening of her book *The Virtual Window: From Alberti to Microsoft*:

> The window is an opening, an aperture for light and ventilation. It opens, it closes; it separates the spaces of here and there, inside and outside, in front of and behind. The window opens onto a three-dimensional world beyond: it is a membrane

[44] Alternatively, as Colomina (1994) puts it, “the house is a system for taking pictures” (p. 311).

> where surface meets depth, where transparency meets its barriers. The window is also a frame, a proscenium: its edges hold a view in place. The window reduces the outside to a two-dimensional surface; the window becomes a screen. Like the window, the screen is at once a surface and a frame—a reflective plane onto which an image is cast and a frame that limits its view. The screen is a component piece of architecture, rendering a wall permeable to ventilation in new ways: a "virtual window" that changes the materiality of built space, adding new apertures that dramatically alter our conception of space and (even more radically) of time. (Friedberg, 2006, p. 1)

For Friedberg (2006), the virtual window is born from the window metaphor proposed by Alberti during the renaissance. The author argues, contrary to what many people imagine, that the point of interest for Alberti's proposal in his treatise on perspective and painting *De pictura*, dated 1435, was not that the image observable through the window would be literally comparable to the image of a painting (p. 1). Instead, windows—and architecture itself—frame and, therefore, delimit a view in the same way that a painting can do (p. 20). Friedberg (2006) investigates the emergence over the centuries of devices that also enable to frame image representations. In the author's formulation, the cinema, television, and computer screens fall into this category, being examples of virtual windows (p. 20).

The basis of the argument developed by Friedberg (2006) is "that the cinematic, television, and computer screens have become substitutes for the architectural window—relies on the virtuality of representational images" (pp. 11–12). The author discerns that part of this argument must be understood as a metaphor but that another part must be taken literally. That is, the virtual window encompasses the metaphor of the window perceived as a screen and, concomitantly, the screen becomes a substitute for the architectural window. Successive transformations of the window in architecture, especially those identified in the modernism, accompanying the effervescence of media and information technology, created the context to consolidate the virtual window; as Friedberg (2006) says, "while my argument does not attribute causality, the coincidence of these changes is marked: the architectural role of the window changed alongside the development of its virtual analogs" (p. 12).

In the following passage, Friedberg (2006) remarks the spatial interpretation of her argument, which is also structuring for this research:

> The cinema screen transferred the sensual isolation produced by the plate glass window onto a virtual register. The cultural force of the cinematic and televisual screen produced an ingrained virtuality of the senses, removing our experience of space, time, and the real to the plane of representation, but in the form of delimited vision, in a frame. In this way, the screen—the film screen, the TV screen, the computer screen—is a component piece of architecture, a "virtual window" that renders the wall permeable to light and "ventilation"[45] and that dramatically changes the materialities (and—perhaps more radically—the temporalities) of built space. A virtual window is reliant not on its transparency but on its opacity; its highly mediated modulation of light provides an aperture: not to a reality, but to a delimited virtuality. The "age of windows" may have lasted four centuries, but the "virtual window" will continue to transform our concept of architectural space. (p. 138)

Thus, the virtual window proposed by Friedberg (2006) is based on the metaphor of a screen with attributes comparable to those of an architectural window, as well as on the perception that the architectural window assumes—especially in modernity—qualities typically inherent to screens (in the different types of media). Here, *metaphors* are understood as substitutions that help to accommodate something new, operating as translators, exchanging one thing or idea for other things or ideas already assimilated (p. 220). As Friedberg (2006) puts it: "Metaphors are proxies, aliases. As a rhetorical trope, metaphor relies on the substitution of one thing for another, a transfer of properties from the plane of the literal to the plane of the figurative" (p. 12).

According to Friedberg (2006), "as a metaphor for the screen, the window proposes transparency, a variable size, and the framed delimitation of a view" (p. 15). Since the author defined metaphors as devices for the construction of cultural reality (p. 12), and, as Picon (2003) stated that cultural constructions could shape human perceptual experiences (as referred to in "2.2.3 Materiality"), a conceptual apparatus to support the virtual window is established. Likewise, this conceptual structure supports the metaphorical architectural element proposed in this research: the digital window, as a variation of the virtual window proposal defined by Friedberg (2006).

As a variation of the virtual window, the digital window does not deny its virtuality. In this sense, it is important to delimit the understanding

[45] Here "ventilation" is used in the same metaphorical sense proposed by the author earlier (Friedberg, 2006, p. 1).

of the virtual,[46] even to discern its relationship with the digital, since these terms are not synonymous, as some suggest.[47] The philosopher Pierre Lévy (1998) states that the word "virtual" comes from the Latin word "*virtualis*," which, in turn, derives from *virtus*, which means "power" or "force," thus linking the virtual to the idea of potency, the ability to become (p. 23). For Friedberg (2006), it is pertinent "to clarify the relation between 'virtual' and the Latin term *simulacrum*—where the image has no referent in the real. 'Virtual' refers to the register of representation itself—but representation that can be either simulacral or directly mimetic" (p. 8).

Digital information, on the other hand, is structured by numerically based systems, which are articulated from binary relationships (0 and 1) and having the bit as minimum unit (Negroponte, 1995, p. 14). Present-time society has witnessed an intense digitization process of the most diverse types of information, as exemplified by Negroponte[48] (1995) when he states that "the mixing of audio, video, and data is called *multimedia*; it sounds complicated, but is nothing more than commingled bits" (p. 18).

The representation capacity offered by the camera obscura, through painting, photography, cinema screen, television, computer, cell phone, among others, is what constitutes the virtuality of these media (Friedberg, 2006). Moreover, the intense digitalization of the last decades has blurred the distinction amid the specifics of each media and has been weaving a convergence around the digital. However, this does not affect the inherent virtuality of the representation of these media, whether they be operated in a digital or analog mode (pp. 10–11). Thus, the digital window does not deny the term "virtual," it just does not use it for the sake of general research framing. Such an approach can be understood as a direct consequence of the

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[46] Picon (2003), for example, points out that the representations of an architectural project, whether performed analogically or digitally, are processes marked by the virtual (p. 107).

[47] According to Friedberg (2006), "perhaps a polemic is needed: before the digital age, there was virtuality painterly, photographic, cinematic, and televisual—and its aesthetics and visual systems cannot be reduced simply to information. There is a long prehistory to the 'virtual' image: mirrors, paintings, images produced by the camera obscura, photographs, and moving-picture film all produce mediated representations in a 'virtual' register. Once the term 'virtual' is free from its enforced association with the 'digital,' it can more accurately operate as a marker of an ontological, not a media-specific, property." (p. 11)

[48] In his book *Being Digital*, Negroponte (1995), in a way, anticipates aspects of the digital window when he makes this prediction, "twenty years from now, when you look out a window, what you see may be five thousand miles and six time zones away" (p. 7).

previously mentioned intense digitalization of information in contemporary times.

Therefore, **the concept of a digital window established here refers to the proposition of a metaphorical architectural element: A window based on the visuality of digital information in the built space**. Furthermore, the idea of a digital window comes into a context of blurring of dualities, establishing a prosthetic relationship with the inhabitant, in an experience based on the concept of materiality proposed by Picon (2003). Consequently, the digital window is a hybrid element that operates a kind of interpenetration between digital information and architectural space. Within this approach, Colomina (1994) brings a Le Corbusier's understanding about the window that, safeguarded contextual differences, is closely related to the concept of digital window established here:

> If the eye is a "tool for recording," the window is, for Le Corbusier, first of all communication. He repeatedly superimposes the idea of the "modern" window, the lookout window, the horizontal window, with the reality of the new media: "telephone, cable, radios, … machines for abolishing time and space." Control is now in these media. (p. 332)

With the concept of digital window, this communication process, linked to the window by Le Corbusier, can also be mediated by digital support. However, it is essential to establish that the digital window concept is not intended to lead to replacing physical windows, but rather to allow the development of devices that seek to expand architectural possibilities in face of advances offered by digital media, in order to support and complement physical windows.

Hence, the digital window concept aims to enable body capabilities to be expanded before the possibilities and demands of contemporaneity. As a prosthesis, the digital window is in line with what Teyssot (2005) says about the body; it "can 'inhabit' the world and enter into transactions with the multiple spheres of comfort, media, and information" (p. 81). Thus, the digital window concept seeks to structure systems and tools exploring and supporting a new way to integrate body, space, and digital information, as a form of envisioning this type of approach, following determined architectural and cinematographic works that, up to a certain point, have already anticipated some issues presented herein.

2.4 Related Works

2.4.1 Architectural Narratives

This section seeks to present architectural works that serve as inspiration and foundation for the digital window concept. Therefore, the related works gathered here, even though they have their particularities and idiosyncrasies, connect, to some extent, to issues relevant to the digital window. In a general analysis, it is possible to perceive that these works incorporate information visuality as a relevant component of their architectural systems; that is, the visuality of information operates as an element of the architectural repertoire.

The three works selected are presented in chronological order: First, the *Philips Pavilion* project at Brussels World Fair (BE), by Le Corbusier and Iannis Xenakis, from 1958, is addressed; then the *Slow House* project in Long Island (US), by Elizabeth Diller and Ricardo Scofidio, from 1991; and, finally, the House of the Future project, in Lisbon, by Architect Tomás Taveira, open to the public since 2003.

The *Philips Pavilion* is a pioneering project combining architectural spatiality with electronic sound, colored lights, and image projections, thus creating an immersive ambiance (Le Corbusier, 1958, p. 200). The pavilion can be included in the tradition of architecture realized in the context of temporary exhibitions. For Colomina (2006), temporary exhibitions have been a great laboratory for architecture, especially for modern architecture. The author also cites emblematic works as examples that foster this tradition, such as *L'Esprit Nouveau Pavilion* (1925) by Le Corbusier and Pierre Jeanneret (1896–1967), the *Barcelona Pavilion* (1929) by Mies van der Rohe (1929), the *House of the Future* (*H.O.F.*; 1956) by Peter Smithson (1923–2003) and Alison Smithson (1928–1993), among many other projects from this context (pp. 201–202).

The *Slow House* project, through an unusual approach, seeks to respond to the demands noticed by Diller and Scofidio in contemporary times. The project arises in a context of leisure appreciation by society, where the vacation home (or weekend home) is an architectural expression of this desire, which has become more intense in contemporary times. In this way, incorporating the landscape becomes a vital design strategy, especially a particular category of landscapes valued by this idealized leisure culture, such as a beachfront view (Diller & Scofidio, 1994, p. 224).

The *House of the Future* project can be framed in both situations, as it is a project born in the context of architecture itself—and domesticity—and as an exhibition object, seeking to reflect on contemporary issues. This search takes place using technology integrated into the domestic space and its specificities to make it more sensitive to aspects such as population aging, accessibility, environmental sustainability, and others.

Among a variety of projects[49] that could be addressed here, choosing these three related works is due to their representative capacity concerning the digital window concept. Such representativeness is justified by several reasons, namely: the pioneering approach of the *Philips Pavilion*; the electronic replication of a view in the domestic context, as in *Slow House*; and by the systemic way of integrating the digital environment into the domestic space, as proposed by *House of the Future*. Therefore, by quickly analyzing these three projects, the perspective is that fragments of the digital window will be identified and delimited. Accordingly, the concept of digital window proposed in this chapter is understood as the result of an accumulative process arising from the relationship between visual information and architectural space.

Philips Pavilion

Multimedia experiences have long been a mainstay in the universe of expositions of the most diverse variety. Friedberg (2006) mentions, for example, as early as 1900, the ten *Cinéorama* projectors proposed by Raoul Grimoin-Sanson (1860–1941) at the Paris Exhibition (p. 211). According to Colomina (2006), architects are usually involved in this type of feat; for instance, Architects Charles Eames (1907–1978) and Ray Eames (1912–1988) were responsible for the video *Glimpses of the USA*, presented in Moscow,

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[49] For example, *ADA* (Bullivant, 2005a) and *Media House* (Bullivant, 2005b), projects already mentioned in “1.3.3 Cybernetics and Intelligence,” among others.

in 1959 (just a year after the *Philips Pavilion*), "projecting it on the seven screens suspended within Buckminster Fuller's geodesic dome" (p. 103).

In this context, Le Corbusier was invited to design the pavilion for the Dutch electronics company Philips in 1956. The *Philips Pavilion* was conceived for the *Brussels World Fair*, held in 1958 (*Expo 58*). The architect's challenge was to design a project that would highlight the company's fields of activity[50] and enchant the audience at the exhibition, emphasizing characteristics such as excellence and capacity for innovation (Kiyak, 2003; Petit, 1958).

With these demands, Le Corbusier expressed, from the project outset, his desire to create an architectural experience mediated by the junction of form, sound, image, and light. This can be noted in Le Corbuiser's statement (as cited in Petit, 1958): "*Je ne ferai pas de façade Philips, je vous ferai un poème électronique. Tous se passera à l'intérieur : son, lumière, couleur, rythme. Peut-être un échafaudage sera-t-il le seul aspect extérieur du pavillon*"[51] (p. 23). For this purpose, the architect gathered his team with Engineer Iannis Xenakis (1922–2001; also credited as author of the project[52]), Musical Composer Edgard Varèse (1883–1965), Filmmaker Philippe Agostini (1910–2001), and Graphic Designer Jean Petit (1927–1999; Centola, 2011; Kiyak, 2003; Petit, 1958).

The design had its traces in plan compared to a stomach by Le Corbusier (Kiyak, 2003, p. 161) and could be inscribed in a rectangle, measuring 25 by 40 meters (Petit, 1958, p. 141). The complex geometry of the pavilion was composed of straight and curved lines, which translated into reinforced concrete vertices and surfaces structured by rods, forming paraboloid hyperbolas. In Le Corbusier's (1958) brief mention about the *Philips*

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[50] The electronic device company had a vast array of activities, ranging from sound components, telecommunication, lighting, and television to x-ray technology (Kalff as cited in Petit, 1958, p. 15).

[51] Le Corbusier said that he would not make a façade to Philips, but an electronic poem, where everything would happen inside the pavilion: sound, light, color, rhythm. Perhaps scaffolding would be the only exterior aspect of the pavilion (Le Corbusier as cited in Petit, 1958, p. 23).

[52] According to Kiyak (2003, p. 162), there was tension over the project authorship. Philips had to step in to get Le Corbusier to accept Xenakis as a co-author. In his book *Œuvre Complète* (1958), Le Corbuiser makes no mention of Xenakis when introducing the *Philips Pavilion*.

Pavilion in the sixth volume of his *Œuvre Complète* collection, the architect describes the pavilion as follows:

> The structure is composed of hyperbolic-paraboloid shells which, up to now, have not been used for problems of this type. The walls are constructed of rough slabs cast in sand moulds on the ground, measuring about 5'-0" on a side and 2" in thickness. They are mounted in place by means of a movable scaffolding and are supported by a double network of cables, 3" in diameter, suspended along the cylindrical directrices of strongly reinforced concrete. Such is the principal of the structure. (Le Corbusier, 1958, p. 200)

According to Açalya Kiyak (2003), the interaction between musical composition and space, and even how the sound equipment allowed coordinating the execution of the musical composition, were prominent points in the project. Furthermore, both Varèse's compositions and Xenakis's (who, after this project, began to dedicate himself to music) were relevant in the early days of electronic music. However, Le Corbusier chose to create a visual narrative independent of sound, which relieved the team from maintaining rigid synchrony between sound and image. Thus, the only link between sound and visual composition was the total duration time, 480 seconds, that is, eight minutes (Centola, 2011, pp. 49–50). This temporal way of working with space inspired the title of an important book on this project, *Space Calculated in Seconds: The Phillips Pavilion, Le Corbusier, Edgard Varese*, by Marc Treib (1996).

Petit (1958) reports that Le Corbusier used different visual composition strategies to create the *Poème Életronique* (see *Figure 2.7*). There was a film in black and white (*Les écrans*), formed almost exclusively by the succession of still images; ambiance effects (*Les ambiences*) provided by the lighting that hit the curved surfaces; two suspended sculptures that received colored light (*Les volumes*); and auxiliary projections juxtaposed to the main screen, inserting images or complementary forms to the main film (*Les tritrous*). There were even moments when lighting equipment simulated the celestial vault. Some of these elements functioned concurrently, while others alternately (pp. 207–209). According to Nicolau Centola (2011, pp. 59–60), the juxtaposition of images is the main point of the *Poème Électronique* visual dimension.

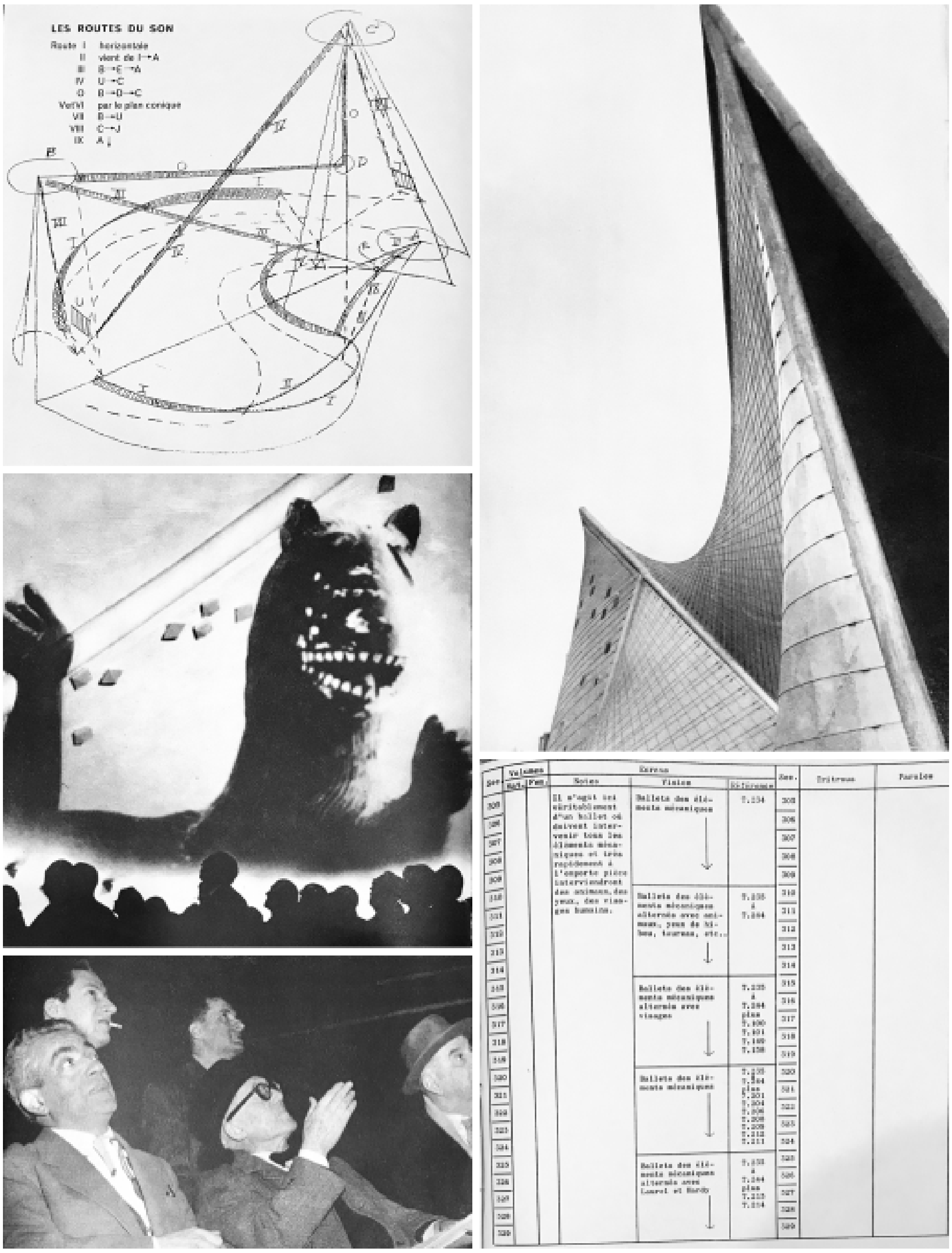

***Figure 2.7** Diagrams, display of the Poemè électronique and image of the Philips pavilion (Petit, 1958, multiple pages)*

Multiple types of equipment, including cinema and light projectors with colored filters, lamps that simulated stars, servomotors, among others, were used to create the visual experience of *Poème Életronique*[53] (Petit, 1958, p. 209). Great care was taken that the images were sufficiently sharp and the colors maintained their saturation and brightness, since there was projected

[53] Safeguarded the due proportions, these components do not differ much from the components used in developing the mechanical part of the digital window, proposed in Chapter 4.

light crossing, which could lead to undesirable changes in the images (Centola, 2011, p. 55; Kiyak, 2003, p. 163).

The video produced by Le Corbusier, having the support of Philippe Agostini and Jean Petit, as mentioned earlier, was divided into seven parts[54] and freely sought to portray an overview regarding the development of humanity, post-war issues, and notes for the future (Centola, 2011). Furthermore, Kiyak (2003) points to influences from Fernand Leger (1881–1955) and Russian Filmmaker Sergei Eisenstein (1898–1948). In a general analysis of the experience proposed by Le Corbusier, the author also notices the influence of the book *Vision in Motion* by Hungarian Artist László Moholy-Nagy (1895–1946).

Kiyak (2003) reports that the *Philips Pavilion* could receive 500 people per exhibition, which lasted 10 minutes. During the six-month duration of the fair, the pavilion received around two million spectators who could experience the media incursion proposed by Le Corbusier and his team. After the demolition of the pavilion immediately after the fair, in 1959, it was no longer possible to reproduce the experience in its entirety (p. 161). However, there are videos made later, based on the superimposition of sound recording registers and the composition of images proposed by Le Corbusier that present, in a partial and limited way, a glimpse of the *Poème Életronique* (Banjokrisis, 2010).

The innovative way the *Philips Pavilion* integrated architectural spatiality and multimedia content made it a relevant benchmark for the digital window concept. Especially for the way the images relate to space, the juxtaposition of visual information, and their expanded and multiple capacities to transform walls into screens.[55] Accordingly, it is also important to

[54] Sequence I (0” – 60”): *Genèse* (Genesis), Sequence II (61” – 120”): *D’Argile et D’Esprit* (Matter and Spirit), Sequence III (121” – 204”): *Des Profondeurs a L’Aube* (From Darkness to Dawn), Sequence IV (205” – 240”): *Des Dieux Faits D’Hommes* (Manmade Gods), Sequence V (241” – 300”): *Ainsi Forgent les Ans* (How Time Molds Civilization), Sequence VI (301” – 360”): *Harmonie* (Harmony), and Sequence VII (361” – 480”): *Et pour Donner a Tous* (To All Mankind; Centola, 2011, p. 60; Petit, 1958, p. 93).

[55] Just few editions after the 1958 fair, at the 1964 *New York International Fair* (*Expo 64*), Colomina (2006) describes that “everywhere at the fair, new media were seen to make possible new environmental experiences, not simply representing the world, but reconstructing it, media becoming the environment” (p. 285).

observe the establishment of a dynamic spatial relationship between the spectator and the various contents that were being presented throughout the pavilion.

Broadly, it is possible to understand that, as the concept of digital window proposes, the *Poème Életronique* demonstrated, in 1958, that information (sound and visual) could be converted into an architectural element, with implications for space. Although it is not possible, at this moment, to accurately describe the impact generated by experiencing the *Philips Pavilion*, Kiyak (2003) argues that "however, what is clear is that in the minds of those who witnessed the spectacle the *Poème Électronique* evoked a totally different sense of meaning, and different sense of space" (p. 164).

Slow House

In their aforementioned book *Flesh: Architectural Probes*, shortly before introducing the *Slow House*, Diller and Scofidio (1994) presented their artistic work *Tourisms: suitCase Studies.*[56] The art installation—already shown at the Whitney Museum of Art—raises questions about tourism and leisure as contemporary society's aspects.[57] These questions, to some extent, precede and underpin the design of the *Slow House* vacation home.

Diller and Scofidio (1994) note the Latin origin of the words "vacation" (from *vacare*, related to leaving space vacant) and "leisure" (also of Latin origin *licere,* referring to license or freedom of action) so as to contextualize the phenomenon of tourism. Along these lines, they point that the vacation home is a product of the bourgeois tourism industry (p. 221). For Diller and Scofidio (1994), "despite the apparent contradiction in terms, the vacation home operates as a mechanism of escape from the everyday and from one's customary identity" (p. 221).

Regardless of leisure to be taken as an antithesis to work, the space and time that separating them has been blurred in contemporary times (Diller & Scofidio, 1994, p. 221). For Diller and Scofidio (1994), the

[56] Both *Slow House* (Diller & Scofidio, 1989a) as *Tourisms: suitCase Studies* (Diller & Scofidio, 1991) are also featured on the architects' homepage.

[57] This is also pointed out by Fernández Lorenzo (2012, pp. 52–53) in "1.2.2 Ways of Living." See footnote 8.

vacation home is originally linked to the idea of a return to nature and, ergo, should represent an escape from civilization. However, the contemporary vacation home has resorted to artificial mechanisms to achieve this goal. One can observe, from the need for mechanical detachment (between New York and the Hamptons, as is the case with the *Slow House*) to devices for controlling and reproducing sight, since "the vacation home, too, is a mechanism that supplies the hungry leisure eye" (Diller & Scofidio, 1994, p. 222).

In the conjecture of vacation homes, Diller and Scofidio (1994) evidence the view as an element of great relevance, especially those related to nature, with emphasis on views facing the water. According to the authors, the real estate market makes this relationship clear when pricing houses according to their views: "'water views,' 'waterside views,' 'waterfront views,' 'protected water views.' etc. The 'ocean view' is the most highly valued of all-the view at its most reductive and most dramatic" (Diller & Scofidio, 1994, p. 223).

Nevertheless, according to Diller and Scofidio (1994), the relationship with the view is only consolidated when the frame of the "picture window" is established, since "the picture window constructs nature and domesticates it"[58] (p. 223). Therefore, the issue of view is fundamental in the *Slow House* design, manifesting itself in different ways. The house is mediated by the windows, from the relationship established between the car rear-view mirror and the garage window when arriving at the house to the contemplation picture window enhanced by the addition of an electronic framing (p. 225; see *Figure 2.8*), which is especially relevant to the digital window concept.

For Diller and Scofidio (1994), the project does not exactly have a front facade, only an entrance door. Upon entering, it is already necessary to choose between going up to the kitchen, dining room, and living room or stay on the same level and head towards the bedrooms and bathrooms (p. 225). Plywood layers were proposed for the side enclosures, maintaining a

[58] Beatriz Colomina (1994) also points the picture window as a device to landscape domestication (p. 315), as mentioned earlier in "2.3 Digital Window."

boat-like shape, as evidenced by the construction of its foundations (see *Figure 2.8*; p. 248). The *Slow House*'s curvature and its concentric slicing emphasize the idea of a slow route, where the view gradually emerges. For the authors:

> The Slow House is simply a door that leads to a window: physical entry to optical departure. At a broader scale, it is a passage from artifice (the city-culture operating at its most apparent) to "nature" (the view-culture operating at its utmost subtlety). (Diller & Scofidio, 1994, p. 225)

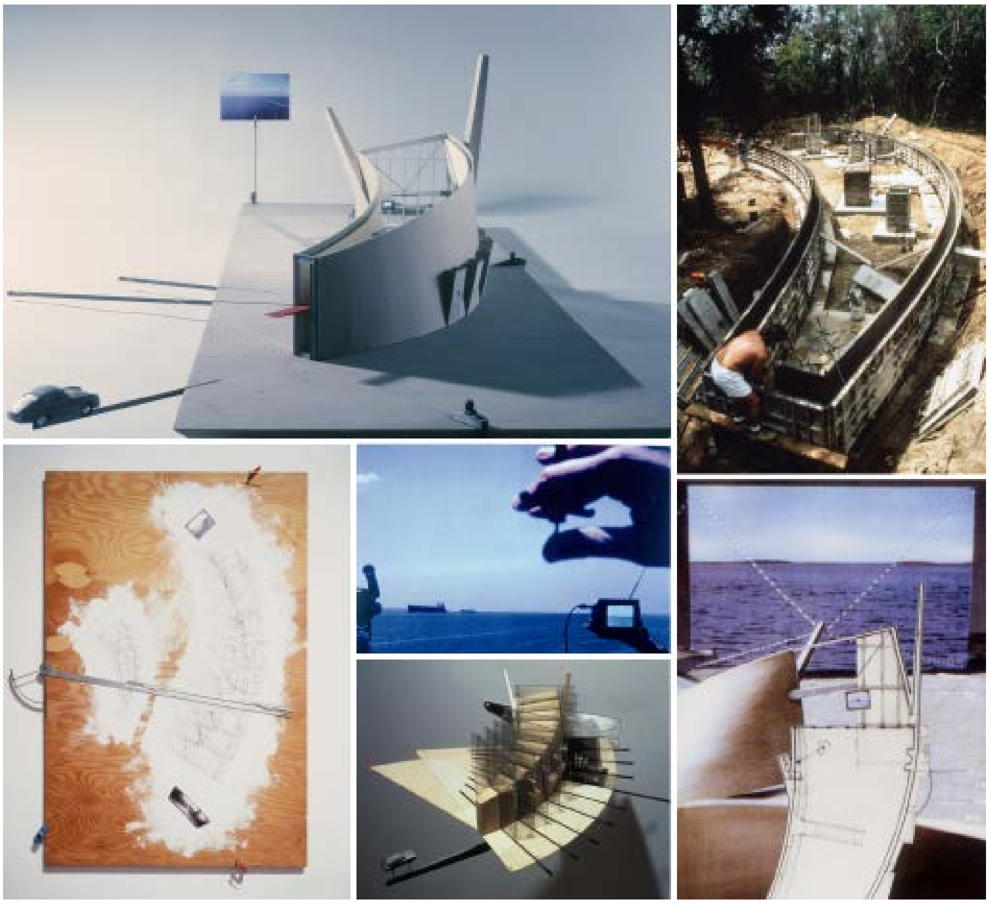

Figure 2.8 *Conceptual schemes and models, and execution of foundations (Diller & Scofidio, 1989a)*

Diller and Scofidio (1994) believe that this vacation home should function as an escape mechanism and that the car rearview mirror, the television, and the picture window already operate as escape devices (p. 224). Due to this, the architects sought to emphasize and relate these devices in the *Slow House* project. The authors' ability to transform aspects observed in contemporaneity into architectural innovation is one of the main reasons for this project to be analyzed as a related work that supports the digital window concept.

As a means of guaranteeing the visualization of the valued “ocean view,” Diller and Scofidio (1994) propose a domestic prosthesis composed of two parts: The first is a video camera elevated to a height of approximately 12 meters (40 feet), directed toward the sea (see *Figure 2.8*) above the vegetation that obstructs this view; the second is a screen installed next to the picture window of the living room, which brings together, juxtaposes, “fits in,” and tames the view of the sea (hitherto obstructed by the vegetation as mentioned earlier). The remote control even allows the device to provide functions such as recording, pausing, zooming, and panning in the landscape, or at least within the portion of landscape view controlled by the prosthesis (p. 226).

Some statements bring *Slow House* closer to the concept of prosthesis discussed in “2.2.2 Prosthesis,” as when Diller and Scofidio (1994) say that “the [*Slow*] house is a mechanism of arousal, eliciting an optical desire and feeding it, slowly” (p. 225). Or when Whitney Moon (2015) declares that “significantly, the Slow House was structured as a machine for viewing nature” (p. 432). In this context, it is noteworthy Vidler’s (1992) statement about the prosthetic nature of Diller and Scofidio’s works[59] when he states that “the object types of Diller and Scofidio neither serve nor dictate; they simply reveal” (p. 158). Thus, it is possible to understand that while the landscape incorporation mechanism brings the ocean view into the house, the house reveals idealized nature, converting itself into an escape prosthesis: a vacation home, in the sense of Diller and Scofidio (1994).

The *Slow House* project approaches the digital window concept when it incorporates external visual information—the view of the ocean in simultaneous transmission—into the house interior.[60] Through the electronic device proposed by Diller and Scofidio (1994), the house (and the picture window) was endowed with a screen-space comparable to a digital

[59] Anthony Vidler (1992) does not mention *Slow House* by name but refers to a body of artwork developed by Diller and Scofidio, many of which were presented at MoMA (Diller & Scofidio, 1989b).

[60] In this context, it is worth mentioning that the article “Towards a Digital Window” (Nogueira et al., 2020), describes processes of transfer and reproduction of the external view incorporated into domestic spatiality in a way comparable to that proposed in *Slow House*; however, using different electronic devices.

window. Therefore, the mechanism proposes to add new information to the view of the picture window, providing a visuality that would not be available in the same way without the prosthetic intervention. In a way, this electronic process of incorporating the landscape does not fail to represent a possible update on the concept of prosthesis in the face of contemporary issues.

According to Moon (2015), although the *Slow House* build was interrupted shortly after the execution of its foundations in 1991, this fact did not prevent the project from having repercussions. It has been published in many books and magazines (it was the cover of "Progressive Architecture" magazine), included in the permanent collection of the Museum of Modern Art (MoMA), and won the P/A Award (p. 440). For the author, the *Slow House* is "significantly, one of the most famous houses of the late 20th century" (p. 440). As this research attests, its project continues to represent an innovative way of dealing with contemporary issues in architecture.

House of the Future

Before approaching the Portuguese *House of the Future*,[61] it is important to remember that the theme "house of the future" is often associated with temporary exhibitions. As pointed out earlier, events of this nature have contributed to experimentation and innovation in architecture (Colomina, 2006, p. 202). According to Colomina (2006), the investigation of the house as a condenser of "future" possibilities dates to the beginning of the twentieth century and was intensified with the massification of electricity, the proliferation of media and telecommunication, among others. For Colomina (2006), "the dream of the future is technological, and the house is its the laboratory" (p. 282).

Many examples can be interpreted as predecessors to *House of the Future*. For instance, *L'Esprit Nouveau Pavilion*, by Le Corbusier and Pierre Jeanneret, in 1925, was already a space aimed at trying to forecast products and technologies with domestic implications, according to

[61] As the project by Peter and Alison Smithson, from the 1950s, in London is also called "*House of the Future*" and has the acronym "*H.O.F.*," whenever this research refers to "*House of the Future*," without mentioning the acronym, it will be referring to the exhibition hosted in Lisbon since 2003.

Architects Peter and Alison Smithson (as cited in Colomina, 2006, p. 202). The *House of the Future* (*H.O.F.*), designed by the Smithsons at the request of the Daily Mail Ideal Home Exhibition in 1956 (*House of the Future*, n.d.), is probably one of the best-known examples in this vein. For Colomina (2006), the *H.O.F.*, more than presenting technological innovations, had the merit of generating a powerful and effective image of the future (pp. 201–204).

The *House of the Future*, based in Lisbon, perhaps brings this dual function of updating an image of the future, as *H.O.F.* did, besides attempting to anticipate systems and equipment in the domestic context, as *L'Esprit Nouveau Pavilion* did. According to information recorded during an in loco visit held on December 2, 2020, under the supervision of Inês Pina, the Fundação Portuguesa das Comunicações (FPC) promoted the exhibition, presenting it as an event arising from the telecommunications sector evolution. Its first exhibition took place in 2002, with the assembly of a stand that explored connectivity through internet access, video calls, online meetings, among others. This first edition of the exhibition became known as "*House of the Future 1.0*."

The information panels at the exhibition inform that only in 2003 did the exhibition gain a house specially developed to contemplate its ambitions. To this end, a large team was formed, gathering more than 40 entities, including companies, universities, and liberal professionals. The architectural project was led by Architect Tomás Taveira and, according to the FPC, it is a post-modernist project. This edition was entitled "*Interactive House of the Future*" ("*House of the Future* 2.0"), expanding the concept of connectivity from the previous edition and promoting an effort for interactivity between visitors and different applications that varied according to the specificity of each domestic environment. Technological applications sought to meet the following aspects regarding domestic life: climate control, energy, entertainment, lighting, security, and surveillance. It is worth mentioning that the house, despite contemplating an idea of future, was based on a program oriented toward a traditional nuclear family.

Informational material of the exhibition mentions that its third edition began in 2004, then entitled “*Inclusive House of the Future*” (“*House of the Future* 3.0”), proposing the use of technology as an inclusion tool. Given that, a room in the house was adapted to be inhabited by an older adult, called “grandma’s suite.” In addition, the house underwent other adaptations to make mobility more inclusive, and it was in this edition that voice commands technology was added to the house. Much of what was incorporated into the *House of the Future* at that time can now be considered commonplace or even outdated. However, in the context of this research, it is worth noting that the exhibition was already attentive to contemporary issues, such as population aging, and pointed to technology as a support for eventual difficulties arising from this phenomenon. Thus, the *House of the Future* intended to present facilitated processes and interfaces (as the voice command) to represent digital inclusion (there is a laptop in the “grandma’s suite”), among other points.

The exhibition panels also inform that the other editions of the exposition were the “*Sustainable House of the Future*” (“*House of the Future 4.0*”), in 2009; the “*Convergent House of the Future*” (“*House of the Future 5.0*”), in 2011; and “*House of the Future in the Cloud*” (“*House of the Future 6.0*”), since 2013. Inês Pina, the professional responsible for presenting the exhibition, says that in each edition, *House of the Future* adds specificities and technologies to its space, depending on the theme proposed. Though, it does not necessarily abandon what was added in previous editions. Nevertheless, Pina reports that a great difficulty has been to reconcile, in the same system, equipment, and subsystems from different origins and different times. In this sense, strategies such as “If This Then That” (IFTTT) have been used. Furthermore, since “*Convergent House of the Future*” (2011), there has been a concern to develop a common interface, seeking, as the FPC states, a “spatial convergence” (according to the exhibition informative material).

The house consists of a large living room made up of different environments, a kitchen integrated into the living room, an attached cinema space, two bedrooms, and a third bedroom (“grandma’s suite”) added to the laundry room, bathroom, and two external spaces for lectures and presentations. The installation has several monitors and television sets spread throughout all its divisions (except for the bathroom). During the visit, 10 screens were counted, but Pina says that this number had already been higher. One of these screens is a small monitor (off) juxtaposed to one of the kitchen windows (see *Figure 2.9*). Such a strategy is reasonably representative of the digital window metaphor, and, in a sense, it resembles *Slow House*.

Figure 2.9 *Pictures of the interior of House of the Future*

During an interview given to this research, on June 4, 2021, in Lisbon, Sociologist José A. Bragança de Miranda[62] mentioned that painting, windows, and television, among other resources, have historically reduced the opacity of walls in a growing process since the domestication of electricity, and which has intensified even more with the digitization of information. These views, also shared by other authors already mentioned herein, such as Colomina (1994, 2006) and Friedberg (2006), for example, are points that contributed to developing the digital window concept in "2.3 Digital Window."

In the article "The 'House of the Future' as an Experience: Problems and Perspectives," Bragança de Miranda (2006) emphasizes the experimental responsibility of events such as the *House of the Future*. For the author, this is an opportunity to scrutinize relationships between domesticity and digital information ("mathematical matrix"). As Bragança de Miranda (2006) states:

> We should not confuse the House of the Future with a show of new technology, nor with something merely amusing or spectacular. It is about regarding it as an experimental space on the limits of human inhabitation when this starts to confound itself with the mathematical matrix. (p. 106)

Thus, the *House of the Future* manifests, within the Portuguese context, a systemic approach to architecture that has, over the years, sought inspiration in the demands and emergences of society to update and reconfigure itself. Emerged as a result of internet advancement and popularization at the turn of the century—like the *Media House* (Bullivant, 2005b)—, the *House of the Future* is significant for the concept of digital window precisely because it seeks to explore digital possibilities in the domesticity, which are eventually manifested through its ubiquitous screens.

2.4.2 Cinematographic Narratives

This section presents three films that, to some extent, illustrate and inspire the concept of digital window; besides, this section highlights the proximity between cinema and architecture. For many authors, these forms of art complement each other (Afonso & Eloy, 2014; Lezo, 2010; Neumann, 1996;

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[62] Bragança de Miranda was part of the *Scientific Committee of the House of the Future of PT multimedia* in 2003 and is the author of the article "The 'House of the Future' as an Experience: Problems and Perspectives" (2006).

Vidler, 1993). In this context, complementarity between architecture and cinema allows a better understanding and visualization of the digital window concept.

As it is widely known, the projection made by Auguste Marie Louis Nicholas Lumière (1862–1954) and Louis Jean Lumière (1864–1948) on December 28, 1895, marks the emergence of cinema (the first so-called scientific exhibition took place in March of the same year), at the *Grand Café*, in Paris (Friedberg, 2006, p. 224). Briefly considered, the technique developed by the Lumière brothers consists of a set of static images presented sequentially, at a certain speed, and exposed to a light source. This set projects light onto a surface, animatedly presenting images. Friedberg (2006) reports that since the advent of the pinhole (whose first records date back to the thirteenth century), part of this mechanism, in a way, was already known. However, with the development of cinema, the opportunity arises to create and edit moving images, exploring the time-space relationship in a hitherto unprecedented way (Friedberg, 2006).

For Architect Denise Lezo (2010), cinema has been an essential instrument for understanding and expressing the world since the dawn of the twentieth century, where its cities and architecture are often portrayed, apprehended, and problematized (p. 16). In the article "The Explosion of Space: Architecture and the Filmic Imaginary," Vidler (1993) understands the relationship between cinema and architecture is evidenced by the role of architecture in the construction of film sets and in "the equally obvious ability of film to 'construct' its own architecture in light and shade, scale and movement, from the outset allowed for a mutual intersection of these two 'spatial arts'" (p. 46). Books such as *Film Architecture: Set Designs from Metropolis to Blade Runner* by Dietrich Neumann (1996) quest to record this tangency.

Many authors see the cinematographic power to fictitiously represent times, situations, buildings, and cities, as an excellent laboratory for architecture (Afonso & Eloy, 2014; Gorostiza, 2001). For Vidler (1993), "the filmic art offered the potential to develop a new architecture of time and space unfettered by the material constraints of gravity and daily life" (p.

46). In this context, sci-fi films are a relevant genre since they are generally concerned with imagining and presenting possibilities of a world yet to come. A considerable number of classic films can be inserted into this tradition,[63] such as *Aelita* (Protazanov, 1924), *Metropolis* (Lang, 1927), *Things to Come* (Menzies, 1936), *2001: A Space Odyssey* (Kubrick, 1968), *Blade Runner* (Scott, 1982), *The Matrix* (Wachowski & Wachowski, 1999), *Minority Report* (Spielberg, 2002), *Ex Machina* (Garland, 2015), *Blade Runner 2049* (Villeneuve, 2017), among many others.

Through special effects and characterizations, cinematographic language, since its incipient stage, has been able to provide visually reliable representations of imagined and fanciful worlds (Afonso & Eloy, 2014). To Michael Webb (1996), founding member of Archigram, sci-fi films are, above all, the autocratic and personal vision of their makers (authors, directors, producers), but which, even so, reflect aspects of one's own time. In the fictitious construction of alternative futures, sci-fi films might occasionally anticipate events, habits, and technologies that later would become real, such as telephone and television (Afonso & Eloy, 2014, p. 187).

The remarkable ability to produce and disseminate images of a hypothetical future—often based on unique architectural forms—makes sci-fi films responsible for visually filling the collective imagination about expectations related to scientific progress. Teyssot (1994) points out this phenomenon when talking about sci-fi literature (which precedes and serves as grounds for sci-fi films):

> With Sci-Fi, a tradition of imaginative response to science and technology is transmitted in a direct line through H. G. Wells, Aldous Huxley, Ray Bradbury, Jorge Luis Borges, Adolfo Bioy Casares, the American Sci-Fi authors, and writers like J. G. Ballard and William Burroughs. After all, Huxley, author of *Brave New World* (1932), was the grandson of Thomas Henry Huxley, naturalist, friend of Darwin, and author of *Evidence as to Man's Place in Nature* (1864). (p. 29)

The digital window concept can be seen in a considerable number of films in the sci-fi genre. Among these, three are quintessential in the context

[63] This audiovisual tradition is not limited to cinema. In this sense, it is notable that there is also a great diversity of sci-fi series. Worthy of mention among them is *Black Mirror* (2011–2019), which presents a problematic future in many of its episodes, negatively impacted by the ubiquitous use of technology, especially AI.

of this research, namely: *Things to Come* (Menzies, 1936), due to its pioneering approach and the visual clarity with which it presents the theme; *Minority Report* (Spielberg, 2002), on account of the way it brings digital information into the domestic space; and, *Blade Runner 2049* (Villeneuve, 2017), for the use of AI as a means to further enhancing this relationship between digital information and domesticity.

Things to Come

The sci-fi film *Things to Come* (Menzies, 1936), released in 1936, was produced by Alexander Korda (1893–1956) and directed by William Cameron Menzies (1896–1957). The 117-minute film is the cinematographic adaptation of the novel *The Shape of Things to Come* (1933) by H. G. Wells[64] (1866–1946). Briefly, *Things to Come* portrays the fictional city of “Everytown” in an interval of approximately 100 years, from Christmas 1940 to 2036. The narrative is marked by successive wars that devastated the known world to present its reconstruction in the sequence. This movement of refounding the world was based on the principles of order, rationality, and belief in technology as a solution to humanity’s problems (Menzies, 1936).

In the last period presented in the film, representing the year 2036, the film creative team[65] develops a vision of what a city would be a century ahead. In this conception, one of the elements used to attract the attention of the spectator, and which is evidenced in a particular scene (see *Figure 2.10*) in its final quarter of the film, is the replacement of the windows by a large interactive flat screen, presented as a “History pictures.” A character, responding to a child’s questions (his great-granddaughter), uses the screen, comparing it to a window, to display images from the past, and announces that the “Age of windows,” after 400 years, was over (as discussed in “2.3 Digital Window,” footnotes 40 and 42).

[64] Renowned English Sci-fi author, cited by Vidler (1993), Teyssot (1994), and Neumann (1996), who wrote several relevant works in the segment, many of which were adapted for cinema.

[65] Director William Cameron Menzies first invited French artist Fernand Léger (1881–1955) to design the film sets, but H. G. Wells disagreed with the artist’s vision. The director then invited Le Corbusier, who declined to participate because he disagreed with the vision of the future thought by H. G. Wells. Finally, László Moholy-Nagy, a professor at the Bauhaus, contributed to part of the set design and special effects (Friedberg, 2006, p. 135).

The “Everytown” of 2036 is an underground city, resembling a large shopping mall lobby. For Friedberg (2006), the set “anticipates the type of ‘mutation in built space itself’ that Fredric Jameson found in John Portman’s 1976 Los Angeles Bonaventure Hotel” (p. 133). In this context, the austere domestic environment is inserted, with reduced and transparent furniture (influenced by an avant-garde modernist aesthetics) where the scene mentioned in the previous paragraph takes place. The screen used by the character of the Great-Grandfather works metaphorically as a window, presenting several images (New York city, buildings, and other characters from the film). In a way, it is possible to relate this device as a kind of electronic memory viewer.[66]

Figure 2.10 *“History picture,” a “window” in Things to Come, 2036 (from the film stills)*

Even though other sci-fi films, such as *Metropolis* (Lang, 1927), have also presented screens comparable to televisions, such devices, in the non-fiction world, were at their embryonic stages of development in research laboratories and did not yet exist commercially in the 1930s. However, the screen already functioned as a technological symbol of the future. In this regard, Friedberg (2006) records the use of screens in *Things to Come*:

[66] Here “electronic memory” makes reference to the theoretical contributions of McLuhan (1964/1994), as discussed in “2.2.2 Prosthesis” and addressed in footnote 33.

> The "history picture" screen, sized for the domestic interior, is only one of many screens in Things to Come. As the film enters into its final rhetorical debate about technology, the character Theotocopulos (Sir Cedric Hardwicke) readies to make a speech against the symbol of technological progress, a "Space Gun" designed to propel two young humans into space. A large transparent surface descends into the public atrium space of Everytown, and a large crowd gathers to watch his five-story-tall "televised" speech against "progress." Cut to Oswald Cabal (Raymond Massey) at his desk pushing back a smaller transparent screen device, bemoaning the broadcast signal: "And that voice is sounding to the whole world." The image of Theotocopulos appears in a subsequent shot on another (vertically oriented) room-sized screen, stared at by two young viewers. (p. 136)

The clear and direct way through which *Things to Come* establishes a visual metaphor of the window with the screen is very relevant to the digital window concept defended herein. Even though the film does not mention any digital aspect of the content presented on its various screens, the work accurately portrays screens as an interactive support of visual information. In this way, *Things to Come* provides an image of a window being compared to a screen (still in the 1930s) and demonstrates its use in everyday domestic life.

Minority Report

The sci-fi film *Minority Report* (Spielberg, 2002), released in 2002, was produced by Gerald R. Molen et al. and directed by Steven Spielberg. The 145-minute film is a cinematographic adaptation of the eponymous short story by Philip K. Dick[67] (2002), originally published in 1956. In short, *Minority Report* is set in the fictional year 2054, in a futuristic Washington (DC). The film revolves around a complex system called *Pre-crime*, which could anticipate murder crimes before they took place and thus preventing them (Spielberg, 2002).

When the protagonist returns for the first time to his apartment, still during the first quarter of the film, he uses a set of electronic devices capable of generating a projection on the wall. Such a projection has qualities that evoke the concept of a digital window. This scene takes place in an integrated domestic environment, a mix of kitchen, living room, and office. In the area next to what appears to be a computer, the main character says "wall

[67] Philip K. Dick (1928–1982).

screen" to activate the projection system via voice command. Subsequently, he inserts a small transparent[68] memory disk, forming the projection on the wall with the chosen memory.

The system also has small light projectors articulated at different points in space, shaping a sort of rudimentary hologram (see *Figure 2.11*). In the scenes presented throughout the film, the holographic feature applies exclusively to human characters, while the background remains a bidimensional projection. In some moments, the main character tries to interact spatially with the holograms, repeating acts and utterances recorded in the disk memories.

Figure 2.11 *The main character manipulates his "wall screen" (from the film stills)*

This group of devices allows one, fictionally, to explore the interaction with digital information within the domestic interior in an even more profound way than that presented in *Things to Come*. Picon (2003) uses this film (among others) as an illustrative example to argument about the experience of materiality in contemporaneity (already discussed in "2.2.3 Materiality"). In this context, the author highlights that many possibilities may emerge from the relationship between physical space and digital information. For Picon (2003):

> Our very perception of space will in its turn be affected by these very physical changes. In films like *Johnny Mnemonic, The Matrix* or the recent *Minority*

[68] Like the "History pictures" in *Things to Come* (Menzies, 1936), the screens of *Minority Report* (Spielberg, 2002) are always transparent. More than six decades after *Things to Come* (Menzies, 1936), it is possible to see that transparency continues to be used as a symbol of futuristic technological advances, addressed by Colomina in *Domesticity at War* (2006) and *X-Ray Architecture* (2019).

> *Report*, cinema has envisaged repeatedly the changes in the perception of ordinary space that should be brought by the development of sophisticated interfaces between the ordinary space and the digital one. The notion of enhanced or increased reality does convey the idea of a different materiality made possible by the hybridization of the physical and the digital. This hybridization is not yet fully there, but some features of the displacement of materiality can be already observed. (p. 109)

Minority Report is relevant to the context of this research precisely because it visually exemplifies possibilities arising from the relationship involving digital information and the domestic space, especially when using the "wall screen" in the scene mentioned earlier, which takes place in the main character's apartment. It is worth noting that this scene presents the character operating electronic devices (prostheses) to perform activities of a highly intimate nature—remembering and trying to visually relive the presence of absent relatives—which are normally sheltered by domesticity. Therefore, space in the fictional narrative of *Minority Report* acquires attributes to enhance the domestic experience through this type of digital window.

Blade Runner 2049

The sci-fi film *Blade Runner 2049* (Villeneuve, 2017), released in 2017, was produced by Andrew A. Kosove et al. and directed by Denis Villeneuve. The 163-minute film is the sequel to the 1982 film *Blade Runner* (Scott, 1982). The first film, produced by Michael Deeley and directed by Ridley Scott, is based on the book *Do Androids Dream of Electric Sheep?* by Philip K. Dick[69] (1996), originally published in 1968. *Blade Runner* is considered a classic of the sci-fi genre (Neumann, 1996). In its sequence *Blade Runner 2049,* the central character is a replicant[70] android hunter located in an overpopulated Los Angeles beset by severe social and environmental problems. In this context, the main character questions replicants' social and moral

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[69] The same author of the science fiction tale that gave rise to *Minority Report* (Spielberg, 2002).

[70] "Replicant" is the term used in the narrative of the films *Blade Runner* (Scott, 1982) and *Blade Runner 2049* (Villeneuve, 2017) to refer to androids. "Android" is a word of Greek origin related to the form of a man (Nascentes, 1966, p. 44) and is a term commonly used in science fiction to refer to machines or robots with a human appearance.

role concerning humans when investigating the birth (and not the fabrication) of a replicant in the past (Villeneuve, 2017).

As mentioned in the article "The Future of the Past: Housing in Blade Runner" (Nogueira & Farias, in press), many of the *Blade Runner 2049*'s scenes take place inside the protagonist's apartment. In the first scene set within this domestic space, one can perceive the operation of an electronic device installed next to the ceiling (see *Figure 2.12*). The device resembles a mechanical arm that allows a sophisticated AI-based hologram[71] to transit through space. If in *Minority Report* the holograms were rudimentary, in *Blade Runner 2049*, they are already highly developed. The holographic character gains even greater spatial freedom through a wireless system as the narrative continues.

Figure 2.12 *Mechanical arm allowing the hologram to move through the domestic space (from the film stills)*

In *Blade Runner 2049*, the holographic character works as a highly developed electronic personal assistant who seeks to improve the inhabitant's domestic experience. An example of this is when, through holography and AI, the holographic character simulates an attractive meal and superimposes the three-dimensionally generated image on the dish that the inhabitant would

[71] Such a holographic assistant is a female character, which can be understood as reflecting the perpetuation of gender inequality also in technological developments (as well as in domesticity, as shortly mentioned in "1.2.1 A Brief Historical and Conceptual Contextualization of Domesticity"). For Crawford (2021), most electronic personal assistants available on the market either have a female name or a female voice. Teyssot (1994) perceives the feminization of the machine as remnants that mix the sexualization of women with aspects related to motherhood (p. 13).

consume. However, the excellence of the technological advances allowed by the fiction of *Blade Runner 2049* notwithstanding, it is possible to say that, in essence, such a system is not so different from what current electronic personal assistants already do.

The holographic fantasy employed in *Blade Runner 2049* makes the relevance of the spatial approach to digital information explicit. Furthermore, the film demonstrates several possibilities that emerge from this approach, related to the domestic experience and its intrinsic activities. Another notable point is the question of the interface proposed in the film, which uses AI to establish its means of interaction with the inhabitant. Moreover, both the use of mechanical devices to provide digital information with spatial movement and the use of AI to interact with the user are pertinent points for developing a system capable of supporting the digital window concept elaborated in this research.

2.5 Conclusion

This chapter collects and relates structuring notions for the foundation and definition of the digital window concept, bringing together related works, where one can recognize and glimpse aspects of the digital window.

In “Like a Second Sort of Body” (2.2), several authors are cited regarding the blurring of certain dualities in contemporaneity, mainly due to technological advances that marked the last centuries, such as the emergence and dissemination of electricity, mass communication, computing, and information technology, among others. It is possible to discern prostheses as part of this context, where the relationship between the artificial and the natural is intensified and confused in certain panoramas. Throughout this process, technological culture was perceived as an agent capable of altering and expanding human experience concerning materiality, not restricting it to physicality.

In “Digital Window” (2.3), it was presented a conceptualization, summarizing the historical evolution of both windows and glass as architectural elements. It also focuses on the modernist picture window, its relationship mediating public and private spaces, understanding it as an architectural prosthesis, especially in Le Corbusier’s work. Subsequently, the concept of the virtual window by Anne Friedberg (2006) as well as the metaphorical approach proposed by the author are analyzed. Together with the concepts already mentioned in “2.2 Like a Second Sort of Body,” these concepts formed the theoretical basis for the digital window concept. Finally, the digital window concept is established as a metaphorical architectural element that deals with the visuality of digital information within the built space.

In “Related Works” (2.4), it was gathered some efforts in which aspects of the digital window concept were identified. These works are divided into two groups, “Architectural Narratives” (2.4.1), and “Cinematographic Narratives” (2.4.2). In the first group, the three highlighted ones are: the *Phillips Pavilion* by Le Corbusier and Iannis Xenakis, where the space gains new properties from the projection of animated visual elements; Diller and Scofidio's *Slow House*, which, among other things, electronically introduces the ocean view alongside the conventional window view; and, FPC's *House of the Future*, designed by Tomás Taveira, where various possibilities and implications from information technologies have been applied to the domestic context.

In "Cinematographic Narratives" (2.4.2), cinema is presented as a means of expression with architectural relevance and, thus, these three films were selected for the ways in which they foresee and represent future possibilities for the digital window concept: *Things to Come* (Menzies, 1936), still in the 1930s, introduced a large flat screen with interactive content as a futuristic window (from the fictional year 2036); *Minority Report* (Spielberg, 2002) illustrates possibilities arising from the application of digital content in the domestic space through projections on its "wall screen;" and, *Blade Runner 2049* (Villeneuve, 2017) intensifies the relationship between digital information and domesticity, adding AI as a preponderant element in the interaction with the inhabitant.

The set of concepts analyzed herein and the authors in question form the leading theoretical framework to establish the digital window concept, which is basal in this research. Subsequently, the related works illustrated possibilities about the digital window and recorded its occurrence, thus concluding the first part of this document ("Toward a Digital Window"). From this structure and related works, it is feasible to proceed to the other stages of the research, presented in "Building a Digital Window" (Part 2).

2.6 References

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[part 2]

Building a Digital Window

Lisbon Context

[chapter]

3

Lisbon Context

This chapter presents and relates data from different sources on demographic aspects recently registered in Lisbon, Portugal. Such data are introduced to contextualize the issue of population aging in contemporary times, allowing to verify evidence concerning some domestic habits and the use of information technology by this population cohort within their dwellings. Therefore, applying different methodological tools to data collection and analysis, this chapter attempts to characterize a possible context for developing and applying the digital window concept.

3.1 Introduction

As the notions regarding the digital window concept have already been established, and its architectural scope can be vast, within the ambit of this research, its possible applications are investigated only in the domestic context. However, it is necessary to structure an application context beyond this boundary. Based on several questions about domesticity in contemporary times and ways of living (dealt in Chapter 1), the group of older adults was chosen as the key population and the city of Lisbon as the research geographical area. These delimitations justify the need to study the specificities of this population in Lisbon to characterize a possible context for applying the concept of digital window (among other contexts that could be explored in further research grounded on the idea defended here).

Also, in "Chapter 1 - Domesticity, Cybernetics, and Artificial Intelligence," some data were introduced, intending to support the issue of population aging as a current and relevant phenomenon, impacting on ways of living (see "1.2.2 Ways of Living" and "1.2.3 Population Aging"). Such data confirm it as a trend verified in Portugal and its capital: Lisbon.

In this third chapter, data from the "Censos 2021" (INE, 2021a, 2021b) are introduced, which confirm and provide more up-to-date information than those provided by the *Atlas Social de Lisboa* (CML, 2017) as regards population aging in Lisbon. In addition, quantitative and qualitative data from other sources are also presented, aiming to investigate issues related to the concept of AiP (addressed in "1.2.4 Aging in Place"), domestic habits, and practice relating the incorporation of information technology resources into the domestic routine of this population group.

In addition to the "Censos 2021" (2021a, 2021b), prepared and published by Statistics Portugal, in its provisional version, this chapter uses data from the "Inquérito à Utilização de Tecnologias da Informação e da Comunicação pelas Famílias – 2020" (IUTICF – 2020; INE, 2020a), also made available by INE, and consolidated data from the survey "Domesticity and Technology[72] in Lisbon" (DTL), prepared and applied within the scope of this research. The DTL survey and INE databases (2020a, 2021a, 2021b) are initially in Portuguese language and, for the sake of clarity, are presented here in English.

The methodology applied to develop this chapter follows the foundations established by Marconi and Lakatos (1985/2002). It is divided into documentary research through consultation of documents and database (p. 65), preparation and application of a questionnaire (p. 98) and form (p. 112), as well as unsystematic observation (pp. 89–90). Then, based on a set of collected and related information, the continuity of this chapter is organized into three main topics, namely:

a) "Population Aging in Lisbon" (3.2): presentation of data collected, organized, and publicized by Statistics Portugal. The information in question confirms the phenomenon of population aging in Lisbon. One can even establish comparisons with older data also provided by INE and recognize the evolution of the phenomenon concerning population aging in the municipality and its metropolitan area.

b) "Domesticity and Technology in Lisbon" (3.3): within the scope of the older population (aged 65 and over), some habits and

[72] The use of the term "technology" was used generically at the survey title as a strategy adopted to simplify the research approach to a broader audience, which is not always familiar with more specific terms.

characteristics regarding the appropriation of domestic space in Lisbon are analyzed. In this context, the presence and use of specific electronic devices are investigated. INE provided part of the data on demand; another part comes from the application of questionnaires and forms, supported by institutions and administrative departments in the municipality of Lisbon.

c) “*Janelar*”[73] (3.4): based on unsystematic direct observations and data collected through the DTL survey, the research quests to verify its occurrence and characterize the habit of staying at the window. Such a habit is recurrently observed in Lisbon (and, probably, in other cities), often practiced by older adults, and serves as an inspiration for developing the research following stages.

Hence, this chapter deals with the verification, qualification, and quantification of certain aspects of population aging in Lisbon. This section attempts to perceive intrinsic characteristics referring to the older portion of the population through the data presented, especially concerning domesticity and its possible involvement with devices for accessing information technology. From this specific cut, the research contextualizes and formats a possible panorama for development and application of the digital window concept in Lisbon.

[73] In this research, the term *janelar* is be kept in Portuguese for consistency with its observation context. As will be discussed later, the term was used in the novel *O Primo Basílio* (1878/2009), by Eça de Queirós. In its English version, the translator Margaret Jull Costa translated *janelar* as “watching from the window” (Queirós, 1878/2011, Chapter III, p. 21).

3.2 Population Aging in Lisbon

This section is based on indirect documents, as it draws on primary statistical sources independent of the research (Marconi & Lakatos, 1985/2002, pp. 62–63). INE collected census data. The majority of the data presented here refer to the "Censos 2021" (INE, 2021a, 2021b), the most recent edition of a long statistical series that seeks to cover the entire population throughout the national territory. The population was subjected to an extensive survey open to participation during part of the first half of 2021. The information collection process was predominantly digital (INE, 2021a, p. 29).

Significant part of the data from INE that are relevant to this research touch on Lisbon Metropolitan Area[74] (AML), and only in some specific contexts refer exclusively to the municipality of Lisbon. Due to their importance for this research, both are reproduced here, always accompanied by the locality's name, to avoid confusion. In addition, some specific indices and data are presented exactly as provided by INE (generally AML data); others, however, were calculated by this research from a database made available by INE (generally data referring to the municipality of Lisbon).

According to INE (2021a), all age groups decreased their population in Portugal between 2011 and 2021, except for people aged 65 and over, which registered a growth of 20.6% during this period (p. 6). Regarding the AML, this group corresponded to 21.6% of the population (620,791 individuals) in 2021 (see *Figure 3.1*), compared to 18.2% (513,842 individuals) in 2011 (INE, 2021b). Within the municipality of Lisbon, according to INE (2021b), the data point to a stabilization, since in 2021 this population cohort corresponded to approximately 23.4% (127,795 individuals), against 23.7% (131,147 individuals) registered in 2011. Such stability can be motivated by several factors, such as economic, social, and health issues. The data may be indicating a trend of transferring part of this population to other

[74] "Área Metropolitana de Lisboa" (and its acronym AML) refers to Lisbon Metropolitan Area.The AML comprises 18 municipalities, including Lisbon, the capital of the country (Skillmind S.A, n.d.). According to the "Censos 2021," the AML had a total population of 2,870,770 inhabitants in 2021, of which 545,923 lived in the municipality of Lisbon (INE, 2021b).

municipalities that make up the AML besides, at the same time, already reflecting human losses due to the health crisis caused by COVID-19.

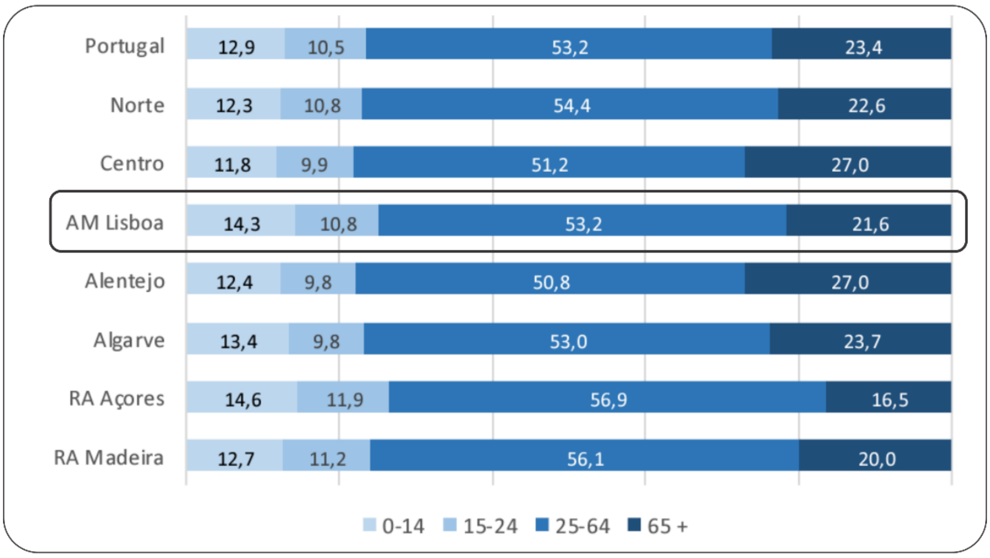

Figure 3.1 *Resident population by age group, 2021 (INE, 2021a, p. 7; emphasis added)*

The gender issue is also relevant, and in this sense, the data indicate that within the municipality of Lisbon 19.3% (49,219 individuals) of men were 65 years old or older in 2021. This portion of the population is even more numerous among women, with 26.9% (78,576 individuals) of the female population in Lisbon aged 65 years or older in 2021 (INE, 2021b). When only this Lisbon's population stratum is observed, it indicates that 61.5% of people aged 65 years or over were female, and 38.5% were male (see *Figure 3.2*). These data are essential when considering the question concerning ways of living and possible public policies aimed at this social segment. Therefore, despite both genders must be considered when characterizing this public, the data evidenced a predominance of females in this population.

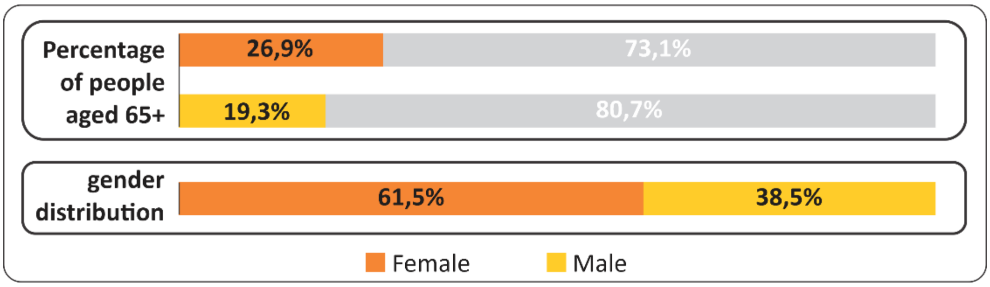

Figure 3.2 *Age distribution by gender in Lisbon (elaborated from INE data, 2021b)*

The aging index (briefly presented in "1.2.3 Population Aging") is also a pertinent instrument for verifying population aging. According to provisional results of the "Censos 2021" (INE, 2021a), the AML presented an index of 117 in 2011, reaching the value of 151 in 2021 (p. 8), as illustrated by *Figure 3.3*. The municipality of Lisbon had an index of 179 people aged 65 years or over for each group of 100 people aged between zero and 14 years in 2021 (INE, 2021b).

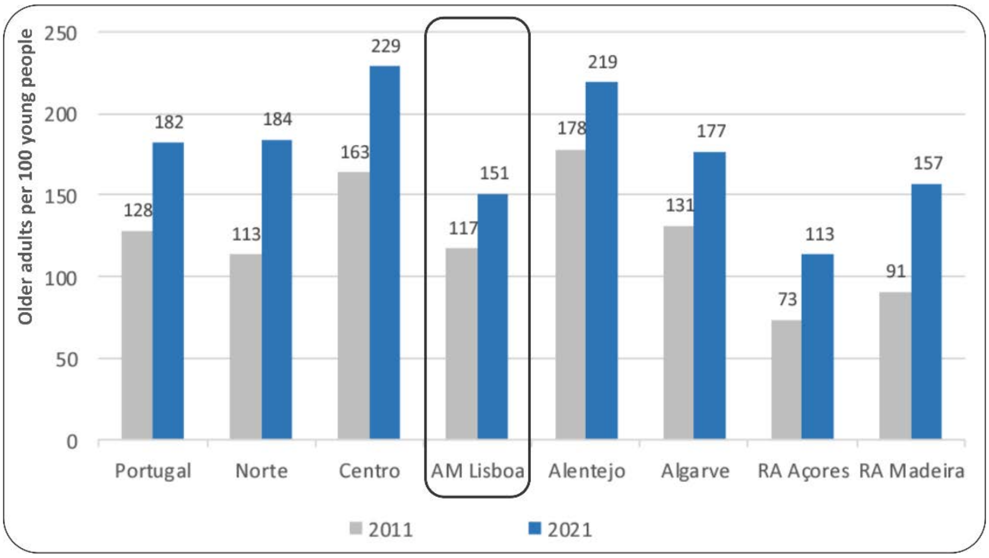

Figure 3.3 *Aging index (INE, 2021a, p. 8; emphasis added)*

The information portrayed confirms the occurrence of the phenomenon of population aging in Lisbon and the AML. This fact is part of the justifications that motivate the interest of this research regarding this specific portion of the population. In this context, it becomes valid the quest to know this audience more deeply, researching some habits and domestic relationships that allow a more detailed understanding of older adults in Lisbon.

3.3 Domesticity and Technology in Lisbon

Since the data presented confirm the phenomenon of population aging in Lisbon and AML, the research uses other data and other methodological tools, seeking to understand some domestic habits and particularities regarding this stratum of inhabitants. Therefore, this section aims to present and analyze data that enable an updated and specific look at the relationship that older adults establish with information technologies and how this happens within their domestic environment in Lisbon.

The first data source that feeds this section was provided by INE, referring to the "Inquérito à Utilização de Tecnologias da Informação e da Comunicação pelas Famílias – 2020" (2020a). According to information provided by "IUTICF – 2020" (INE, 2020a), this survey takes place annually and is based on representative samples. In 2020, data collection was carried out between April 21 and August 31. The sample consisted of 5,094 households spread throughout the national territory, with at least one individual aged between 16–74 (p. 13).

This research implemented request "PED-512720646" to the INE on July 12, 2021, soliciting data exclusively about the populational proportion between 65–74 years old residing in the AML (74 years was the maximum age limit included in the "IUTICF – 2020"). INE partially fulfilled the demand, and the data feeding this section were made available on November 3, 2021 (such data can be consulted in their entirety in "Annex A").

Data provided by INE (2020a), as regards the "IUTICF – 2020," indicate that 82.6% of households with people aged 65 years or over residing in the Lisbon Metropolitan Area had internet access in 2020, 79.3% having broadband access. The surveys also report that 58.2% the cohort between 65–74 years old residing in the AML used the internet during the three months prior to the interview (practically the same rate [58.8%] when checking at the last 12 months preceding the interview). The research shows that access was uneven as for different genders and levels of education. The internet access rate displayed 67.9% among male participants and 51.1% among female participants, reaching 96.1% among those with higher education, compared to 42.7% among those having only primary education (third cycle).

INE's data point to a great diversity of online activities carried out by people between 65 and 74 years old residing in the AML who used the internet in the three months prior to the interview. Exchanging instant messages was the most common activity, with 82.8% of the people in this group doing it. Subsequently, the most performed activities were: searching for information on the internet about products or services (76.8%); reading news in newspapers, online magazines, or other information websites (76.5%); sending or receiving e-mails (73.3%); searching for information about health (53.8%); participation in social networks (53.4%), making telephone or video calls (51.5%); listening to music (47%), among others. Another chart from this same survey reveals that 9.5% of the people in this group made some online purchase within the three months preceding the survey. This rate rises to 11.9% when considering the previous 12 months.

Regarding the use of equipment or systems connected to the internet, the "IUTICF – 2020" reports that 44.6% of people between 65–74 years old residing in the AML used this type of device in 2020. Equipment related to entertainment stood out from this type of use, and television connected to the internet was the system most used by respondents in this stratum of the research (32.5%). Broadly, one can affirm that the data provided by the INE show that the older adults covered by the research and residing in the AML, for the most part, have an internet connection, even if still unequally. The data also showed a diversity of uses, being the main uses of internet related to communication, information, and entertainment.

The second data source that feeds this section is part of the information collected by this research through the elaboration and application of the "Domesticity and Technology in Lisbon" survey (which can be consulted in its entirety in "Appendix 3A"). It consists of a set containing objective multiple-choice questions divided into five sections aimed to address the research concerns. "Section 1" deals with the participant's identification in terms of age, gender, location of residence, origin, and other information (as participation is anonymous, their name is not requested). "Section 2" quests to define participants according to their type of dwelling, length of residence in the same dwelling, if they live with someone else, among others. “Section 3” investigates some of the participant’s domestic relationships, such as how much time they believe they spend inside the dwelling per day, in which part of the residence they spend most of their active (awake) time, and their main daily domestic activities. “Section 4” seeks to register whether there is and how the domestic use of internet and some electronic devices occurs. Finally, “Section 5” brings questions related to the AiP, such as, for example, if the participant would like to move to another place; or if they would rather be in their current dwelling or moving to an assisted living home (nursing home).

The same survey was applied in two versions, as advocated by Marconi and Lakatos (1985/2002); therefore, in a form version, that is, with a face-to-face application (p. 98), conducted in Lisbon, and in a questionnaire completed remotely (p. 112), in an online environment, using the support of the *Google Forms* platform (https: //www.google.com/forms/). As many of these questions were conditional, the survey ranged from a maximum of 56 questions to a minimum of 25 questions. The participant could opt for not answering some questions without this preventing them from progressing in completing the survey.[75]

The survey was carried out throughout 2020, following the recommendations of Marconi and Lakatos (1985/2002), and was adjusted in 2021, after the pre-test stage. The pre-tests of the online questionnaire took place between October 2020 and June 2021. The pre-test phase was supported by the supervisor of this research, Professor Luís António dos Santos Romão, from FA.Ulisboa, Ph.D. in Architecture from MIT, US, and Professor Stella Câmara, from the Instituto Superior de Ciências Sociais e Políticas (ISCSP), Ph.D. in Social Gerontology from the University of A Coruña, Spain. The face-to-face pre-test of the form took place on June 12, 2021, at Jardim Avelar Brotero (Alcântara, Lisbon), with five anonymous volunteer

[75] This freedom given to the participant eventually resulted in a fluctuating number of answers. However, the number of people who did not answer a specific question was very skimpy, as can be seen in the data provided in “Appendix 3B.”

participants.[76] It seems noteworthy that the pre-test stage is a recommendation by Marconi and Lakatos (1985/2002, p. 100), which led to improving the questions contained in the final survey.

Support was sought from institutions and administrative bodies in the municipality of Lisbon to disseminate the online questionnaire. The selection criterion adopted was to look for institutions of recognized relevance in dealing with the target audience—people aged 65 and over—and the administration of the seven parishes with the highest proportion of people aged 65 or over in their population, according to the *Atlas Social de Lisboa*[77] (CML, 2017). In this way, the research resorted to telephone contact, by email and, in many cases, in person, with the parish councils of Olivais, Ajuda, Benfica, Alvalade, Alcântara, São Vicente, and Campo de Ourique (as mentioned in "1.2. 3 Population Aging"), and with the Universidade Sénior da Ajuda, the Universidade da Terceira Idade do Lumiar (UTIL), and the Santa Casa da Misericórdia de Lisboa (SCML).

It is significant that this process occurred in parallel with the health crisis caused by the COVID-19 pandemic, which impacted both the form of access to institutions and the target audience and, consequently, the research schedule. After obtaining support in disseminating the survey within the parish councils of Olivais, Ajuda, Alvalade, and Campo de Ourique, besides the Universidade Sénior da Ajuda and SCML, 79 questionnaires were completed between 13 July 2021, and 14 November 2021.

SCML, through its Unidade de Inovação Social e Transferência de Conhecimento (UISTC), granted access to the Unidades de Desenvolvimento e Intervenção de Proximidade (UDIP). In this way, the research had face-to-face access to day centers, social centers, community development centers, and intergenerational centers (see *Figure 3.4*) between September 28, 2021 and November 26, 2021. In addition, it is notable that the UDIP boards listed in which units it would be possible to apply the form based on

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[76] The data from these participants were used only to test the form and are not part of the total survey sample.

[77] It is worth mentioning that this decision was based on data from the "Censos 2011" that fed the *Atlas Social de Lisboa* (CML, 2017), as mentioned in footnote 9 since, at the time, the data from the "Censos 2021" did not yet exist.

criteria specific to the UDIP once the research was available to visit all possible equipment. On this opportunity, 16 visits took place in 12 units of eight UDIP, totaling approximately 108 hours of data collection, which allowed the questionnaire application to 206 volunteer participants (on average, 30 minutes of contact with each participant,[78] within the stipulated by Marconi & Lakatos, 1985/2002, p. 100).

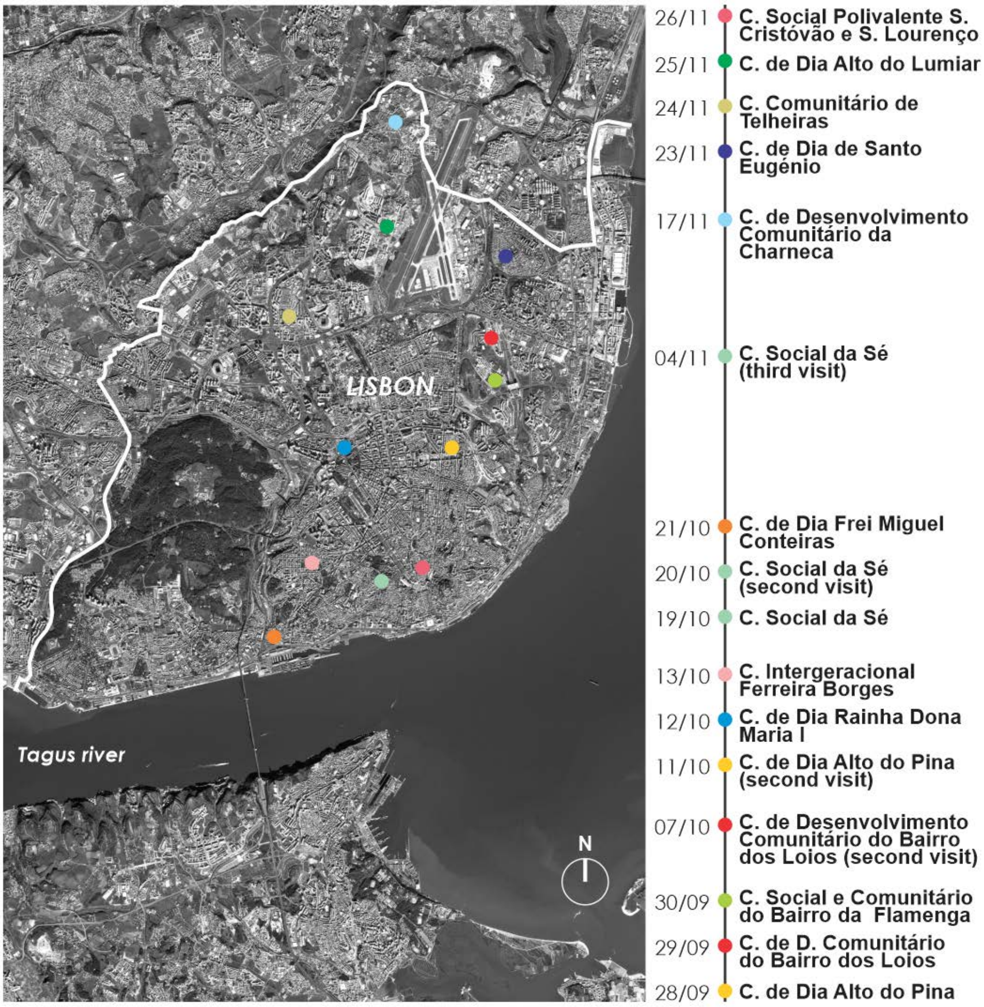

Figure 3.4 *Location and date of application of the DTL survey form (base satellite image from https://pt.wikipedia.org/wiki/Geografia_de_Lisboa#/media/Ficheiro:Lisbon_SPOT_1015.jpg, retrieved December 18, 2021)*

The methodological diversity of dissemination of the survey—between online questionnaires and face-to-face forms—enabled the observation of some differences between an audience, which somehow already had contact with the internet (since they used the digital medium to answer the

[78] Completion of the online questionnaire, when performed without interruption, was stipulated between seven and 10 minutes; however, in its form face-to-face version, this time was extended since, in general, face-to-face dynamics demand more time due to interpersonal interaction.

questionnaire), and another audience that is eventually still digitally excluded. This diversity of survey dissemination motivated the graphic presentation of the data collected in three parallel versions. Therefore, whenever graphic information regarding the DTL survey is inserted, information related to online questionnaires is first included, followed by the data from face-to-face forms and, finally, the sum of both, the total sample. Concerning the values reported throughout the text, the percentiles most often refer to the total sample, and when they cite exclusively the sample resulting from online questionnaires or face-to-face forms, the data origin is properly identified. The complete survey data can be viewed in “Appendix 3B.”

It is noteworthy that the data gathered by applying the survey, in any of its methodologies, do not shape a representative sample of the key population, configuring a non-probabilistic sampling (Barreiros, 1984; Guerra, 2012; Nazareth, 1981). Hence, the data presented is intended to illustrate an overview based on the total sample of 285 participants, formed by the aggregate of the samples composed of 79 questionnaires completed online (27.7% of the total sample) and 206 face-to-face forms[79] (72.3% of the total sample). However, even for reasons of research framing, this total sample is not intended to generalize to the entire population of Lisbon, as it does not follow and does not meet the methodological assumptions necessary for this (unlike what proposes the data provided by INE, 2020a, for example).

According to data from the DTL survey, the total sample was predominantly composed of Portuguese citizens (98.6%), as foreign participants did not exceed 2% of the sample. Those participants lived in 19 of the 24 parish councils in Lisbon, demonstrating a good geographical spread of the survey across the municipality. The proportion of participants who stated that they resided on the outskirts of Lisbon (municipalities of the AML) corresponded to 2.1% of the total. Among the parishes of Lisbon, Marvila was home to the most significant proportion of participants

[79] The sample of 206 participants who answered the form in person, as mentioned, is not enough to allow statistical generalization about this population cohort in relation to the entire city of Lisbon. Nonetheless, it is sufficiently representative within the universe of the public aged 65 and over, who are users of the support services provided by SCML. Thus, providing the information collected to the UISTC may interest SCML besides to configuring a counterpart of this research, so well-received by said institution.

(23.2%), with emphasis also on Campo de Ourique (17.5%), Olivais (11.9%), and Santa Clara (11.6%).

In line with the female predominance in the population indicated by the data from the “Censos 2021” (INE, 2021b), mentioned above, the input collected by the DTL survey also found a higher number of female participants (76.4%), compared to the male gender (26.3%). Furthermore, as the *Atlas Social de Lisboa* (CML, 2017) highlighted, the information also pointed to a large fraction of widowed people (see “1.2.3 Population Aging”). When asked about marital status, most participants identified themselves as widowed, totaling 45.8% of the sample, and the alternative “married,” the second most chosen, represents only half the number of widowed individuals, corresponding to 22.5% of the participants. These data are closely related to the fact that half of the sample claimed to live alone, more precisely 50.9%.

As already briefly discussed in “1.2.2 Ways of Living,” and as the data collected by this research has statistically confirmed as well, the profile formed by female people living alone must be regarded; because even if it is not the only profile, it is the most numerous as age advances. Therefore, questions about possible inadequacies concerning the housing model provided by the real estate market, which focus on a traditional nuclear family (Marques Pereira, 2004) become more evident for this population stratum. The data collected also show that 41.8% of the sample lived in a dwelling T2 type and 30.5% in a T3. The summation of these data indicates that 72.3% of the sample lived in properties with capacity for a plural number of inhabitants. However, as previously mentioned, 50.9% lived alone, evidencing a mismatch.[80]

The data collected also point to a relatively uniform distribution among the three established age groups (from 65 to 74 years old, from 75 to 84 years old, and those over 85 years old). The portion of those who declared

[80] The survey also recorded that 67.4% of the sample perform domestic housework (work that traditionally falls more heavily on women). If a context is imagined where the passing of the years can lead to an aggravation of certain limitations to the body, having to take care of a large house can lead to wearing and tearing besides risks regarding avoidable accidents. However, this is not a working topic for this research, and therefore it is only addressed in this footnote.

to be between 75 and 84 years old corresponded to 41% of the sample, followed by those between 65 and 74 years old, which represented 33.2%, and ultimately, those from 85 years old on, corresponding to 25.8% of this total (see *Figure 3.5*). Even though it was a minor number, having a quarter of the sample aged 85 years or older confirms the tendency of the population to be made up of an increasingly significant number of people of very advanced age (as mentioned earlier in “1.2.3 Population Aging”), which has implications for many spheres of society.

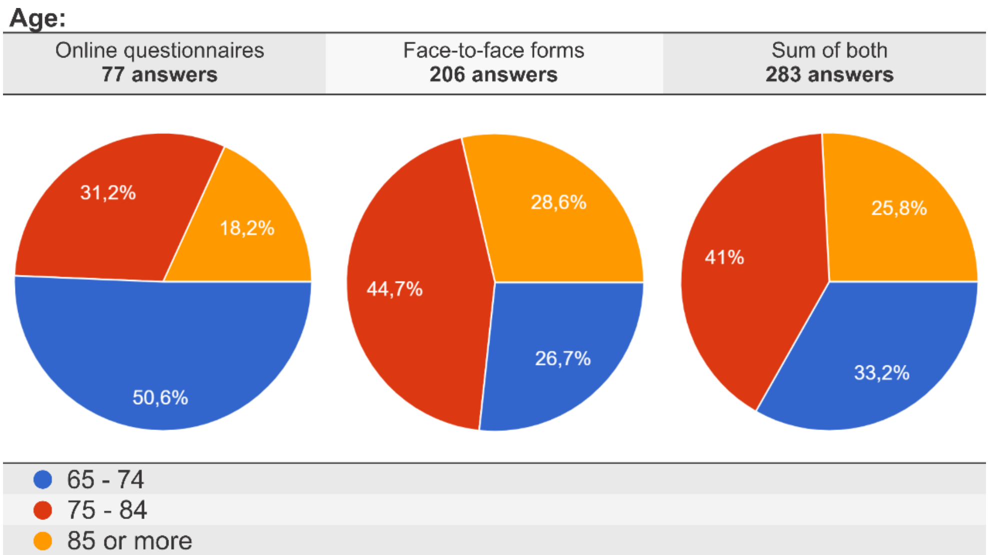

Figure 3.5 *Proportion of age groups, DTL survey*

The data collected indicate that the bulk of participants lived in apartments (96.1%). Other information from the survey indicate that 36.1% said they spent at least 16 hours per day inside the house, 27.7% spent at least 20 hours, and 16% spent practically 24 hours inside the house. If the data as to those who said they spend at least 20 hours within the household are added to those who informed they spend practically the whole day, there is an aggregate of 43.7% of the sample, a very significant amount. These data confirm that this is probably the age group that spends more time in the domestic space, as predicted by Burton et al. (2011). This fact is relevant to the understanding of domesticity in contemporary times, thus being one of the justifications for including this age group as an object of study in this research.

The survey sought to determine in which part of the dwelling people spend most of their active time (when they are awake). The living room was the domestic space indicated by 62% of the sample as the one where they most prolongedly stay (see *Figure 3.6*). This data is consistent with the information that 88.4% of the sample have leisure as their main daily activity and that it, as will be shown later, can be related to electronic devices that are normally housed or used primarily in the living room. Still, on the main daily activities, 87.4% said they also dedicated themselves to preparing food and eating, 79.6% practiced resting, and 67.2% did other domestic work[81] (see *Figure 3.7*).

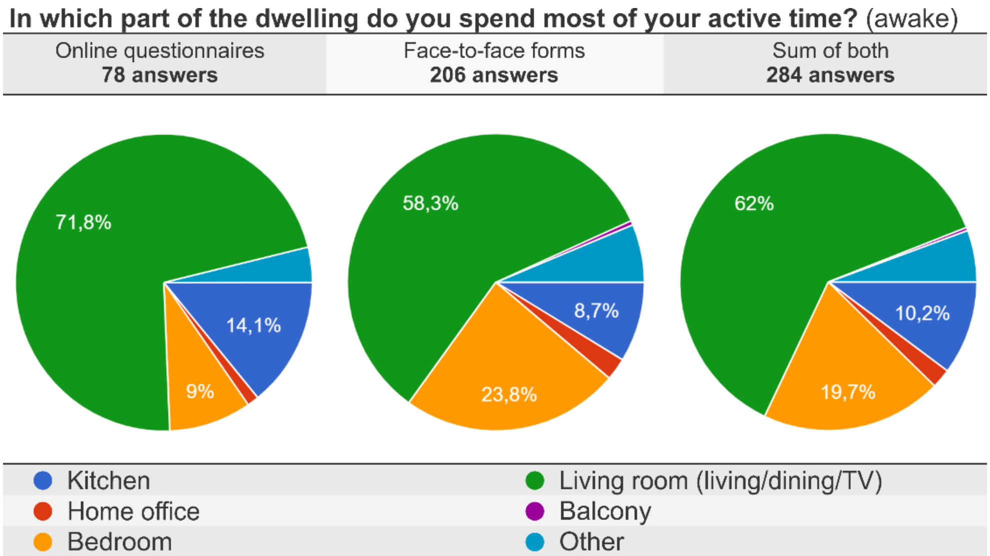

Figure 3.6 *Domestic space where most of the active time is spent, DTL survey*

Regarding electronic devices, the survey sought to record the existence and possible use of the following devices: landline telephone, mobile phone, tablet, television, and computer. According to the data obtained, 98.9% of the dwellings had a television. Subsequently, 90.2% of the participants claimed to have a cell phone, and 76.8% affirmed to have a landline. Furthermore, the computer was present in 31.3% of the homes, and finally, 20% of the sample declared to have a tablet.

When asked about the frequency of use of the devices, 87.9% of those who claimed to have a television said they watched it often. Next, the cell phone was the device most frequently used (60.9% of those who stated to have it), followed by the tablet (57.1%), computer (42.7%), and, finally, the landline phone. (38.8%). The survey information show that, even though

[81] The sum of the answers exceeds 100% statistical, since the participants could choose more than one item as an answer. This situation was repeated in seven other questions of the survey.

cell phones are a much more recent device than landline phones, they are already present in more homes and are used even more frequently when compared to the latter. Tablets and mobile phones displayed significant usage rates; however, television still predominates as the device most used by this stratum of the population when considering the survey sample.

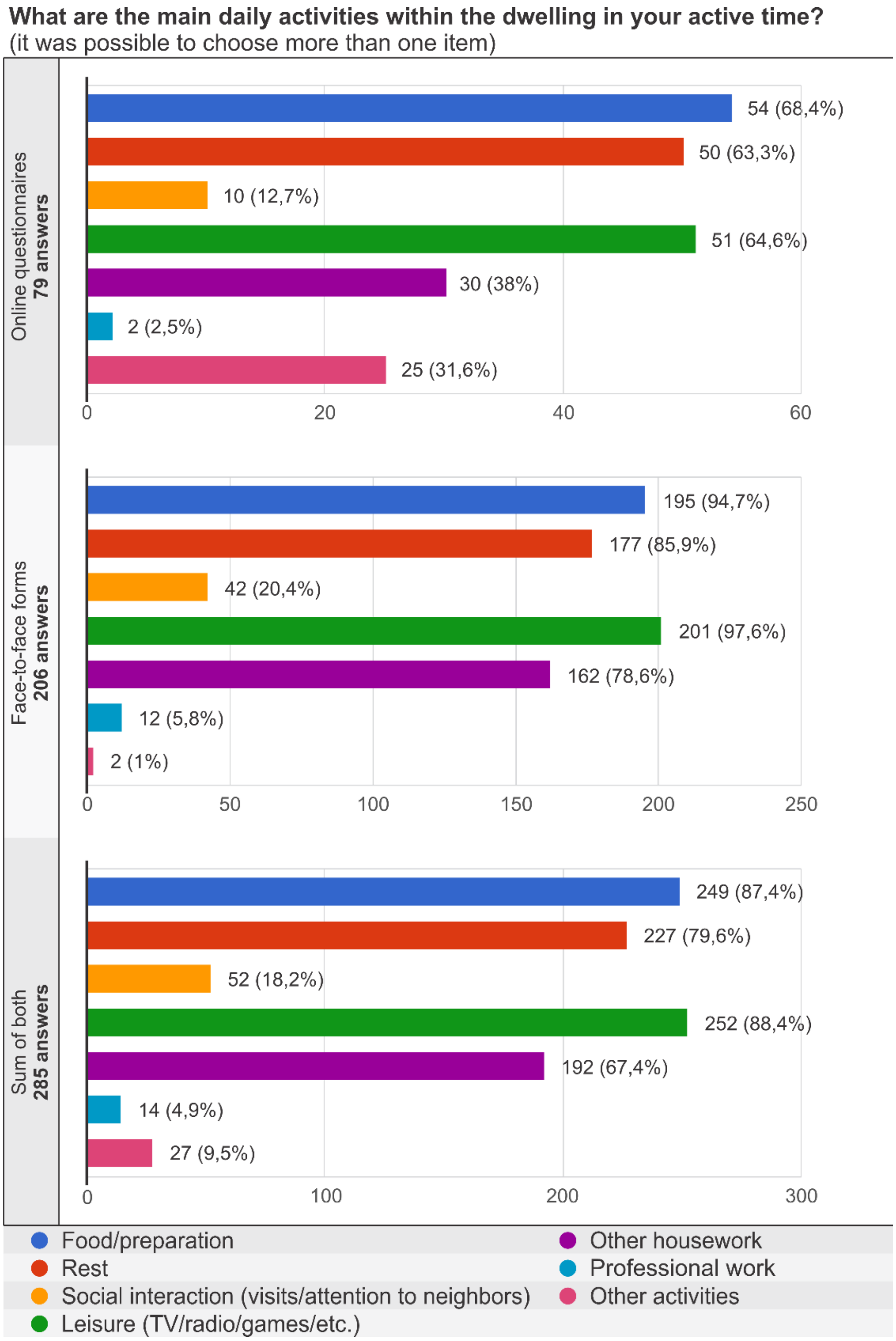

Figure 3.7 *Main daily activities carried out in the domestic context, DTL survey*

As previously mentioned, the living room is the domestic space where most of the sample stated that they spend most of their active time. In this sense, it is significant that, except for the computer, all other devices had their use mostly related to the living room when asked in which part of the dwelling they used the respective devices. According to data collected through the DTL survey, 70.1% of the sample, formed by those who declared to watch TV frequently, did so in the living room. The same goes for 61.8% of those who said they used a landline phone often, 54.4% out of those frequently used their cell phone often, and 50% of them informed they used the tablet often. In the case of computers, 50% of the sample that said they used it frequently pointed to the home office as the main space of use, while 39.5% of the sample said they used it preferentially in the living room. It is still worth noting that mobile phone, tablet, and most computers[82] are portable devices, easily transportable to any part of the house.

In the universe of those who said they used television frequently, 37.8% did so for at least three hours, 30.1% for at least six hours, and 14.2% for eight hours or more. In this sense, the time spent using the computer is also considerable: 50% of those who used the computer frequently said they did so for at least three hours. As for the tablet, 40.6% of the sample that said they used it frequently stated that they used it for three hours or less, and the same proportion declared they used it for an hour or less. According to the survey data, both cell phones and landlines are faster to use, but cell phones are used for longer than landlines, since 31.6% affirmed they used cell phones for three hours or less, and 60.6% told they used them for an hour or less (the minor fraction of time recorded by the survey). For landlines, these rates reach 15.3% and 84.7%, respectively.

The survey data showed that among those who declared to have television, 73.1% owned Smart TVs (and 47.7% had analog television). As for computers, 88.6% said they had a notebook (and 14.8% had a desktop). Regarding cell phones, 62.7% said they had the traditional model (and 37.3% had a Smartphone). Here it is interesting to note that, when considering only

[82] The survey showed that according to those who claimed to have a computer, 88.6% were identified as notebooks, while 14.8% typified them as desktops (this was another one among eight questions that could have more than one answer selected).

the sample of those who answered the online questionnaire, the predominance is reversed, with 57.3% stating to own a smartphone-type cell phone (and 42.7% using the traditional model). In all these questions, participants could mark more than one item, as they could have more than one device, such as, for instance, having more than one TV set (58.3% of those who claimed to have a TV), and these, potentially, could be of different types. This explains why the sum of the percentages exceeds 100% in many of these questions, as also mentioned in footnote 81.

Regarding internet access, 50.7% of the total sample claimed to have internet access, rising to 74.4% when only the data from those who responded to the online questionnaire are observed (which was already expected). Due to methodological differences, it is not possible to establish a direct comparison with the numbers provided by INE (2020a). Although, the percentage of people with internet access verified by the survey is lower than the 82.6% of households with verified internet access by "IUTICF – 2020." It is worth remembering that INE data refer to AML, and the age stratum of this specific data was limited to older adults ranging from 65 to 74 years old. In the case of the survey conducted in this research, the age group includes people aged 65 and over and is focused only on the municipality of Lisbon, as already mentioned.

Nevertheless, it is interesting to note that INE data (2020a), as previously discussed, pointed to unequal access to the internet, with a reduction in internet access among women and people with fewer years of schooling. Accordingly, the total sample of the DTL survey, as mentioned earlier, is primarily female (76.4%), and there are indications that part of the sample is composed of people having low education levels, which, occasionally, could justify this data discrepancy.[83] Regardless, the survey conducted by

[83] As mentioned earlier, the methodological diversity of the survey application allowed a comparison between the group that responded to the online survey and the group that responded in person. The survey does not explicitly address issues related to income or schooling, as it is not a focal point for this research, and so as not to run the risk of creating questions that could embarrass the participants. However, some data and facts may suggest that those who answered the online questionnaire had a higher income and education standard than the group that answered the form in person. For example, the fact that 64.6% of the participants within the online sample claimed to have their property, and 54.2% had an elevator. In the group that answered the form in person, the number of owners dropped to 34%, and as regards those who claimed to have an elevator available, it dropped to 37.3%. In respect to education, it is assumed that all online participants knew how to read, whereas, among the participants of the face-to-face form, participants who voluntarily mentioned not knowing how to

this research showed that half of its total sample has internet access, which is a very relevant figure.

When analyzing internet usage habits, practically half of the sample of the DTL survey who claimed to live in a dwelling with internet access used it frequently (50.7%), had an email account (54.2%), and were part of some social network (51%). The information that half of the sample had internet access at home, half of them affirming to use it frequently, is a significant number, evidencing a considerable dissemination of the internet in this group. On the other hand, this quota also evidences a relevant proportion of the sample without internet access, indicating the persistence of digital exclusion in this group.

The main reasons for using the internet were for communication in general (71.2%), entertainment (68.5%), social networks (58.9%), and as a source of information (53.4%), as presented in *Figure 3.8*. The "IUTICF – 2020" also investigated the activities most carried out on the internet (as already registered at the beginning of this section). Nonetheless, in addition to the reasons already mentioned that make inappropriate a direct comparison between the data obtained by both surveys, the way to formulate the question and the answer alternatives are different here. However, analyzing the data obtained by the two surveys, it appears that communication, entertainment, and the search for information were the main reasons for older adults to use the internet.

According to data from the DTL survey, 58.9% of the sample that said they used the internet frequently did so in the living room (see *Figure 3.9*). Among those who said they used the internet frequently, 56.2% said they used it for at least three hours, while 17.8% used it for at least one hour, and 16.4% declared they used it for at least six hours. The primary device used to access the internet by this group was the smartphone (80.8%), followed by computer (64.4%) and tablet (39.7%). Even though most of the participants reported possessing a Smart TV, the sample of those who

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read were not rare. This perception, to some degree, confirms the inequality as to internet access already verified through the data provided by INE in the "IUTICF – 2020" mentioned earlier. For example, in the DTL survey, 72.4% of those who answered via questionnaire and had access to the internet said they used it frequently, against 36% of those who answered the face-to-face form.

claimed to use the internet frequently showed that only 12.3% of them claimed to use it for this purpose. Additionally, Smartwatch was mentioned by only 4.1% as a device used to access the internet, showing that this type of wearable is still not common within the sample studied.

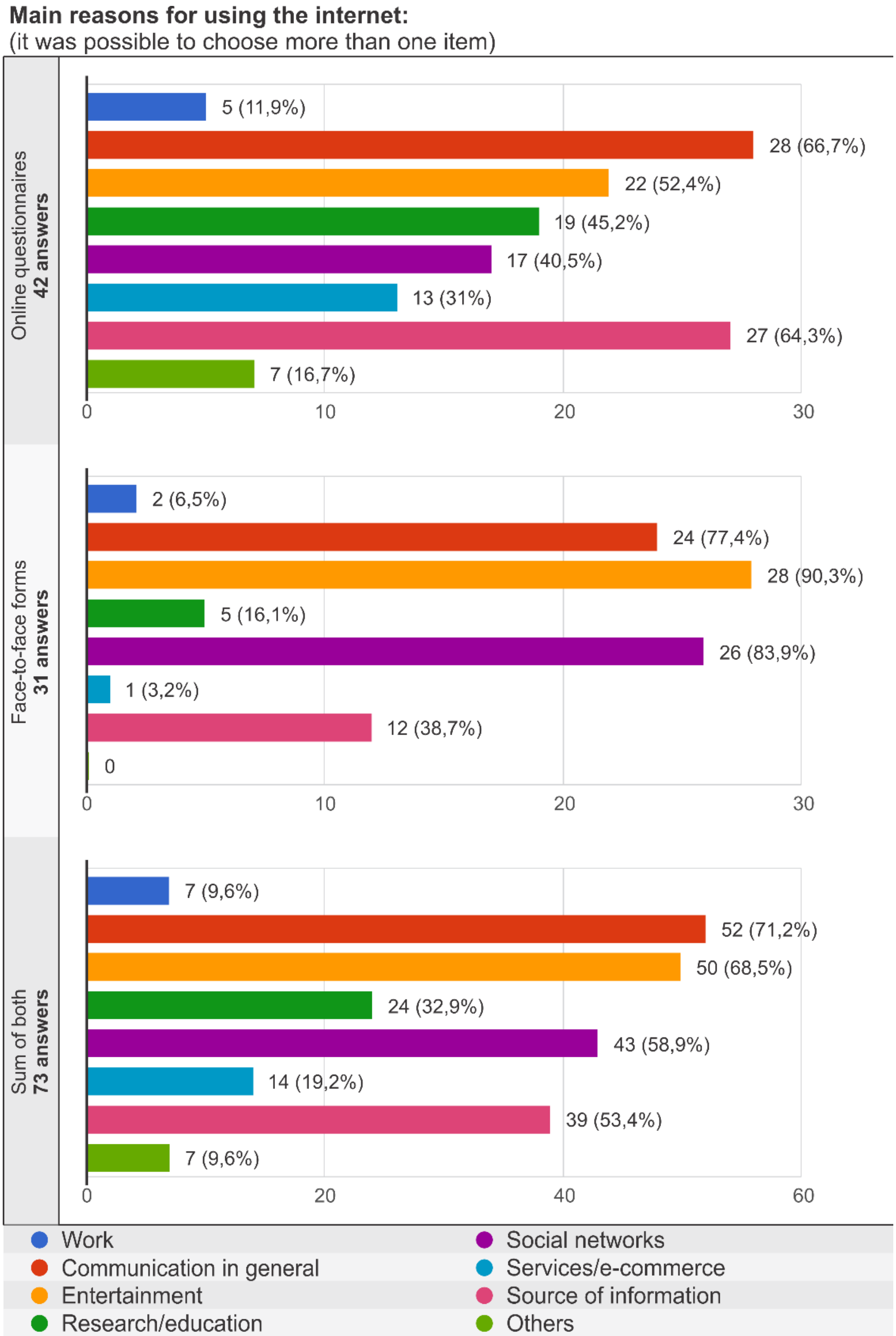

Figure 3.8 *Main reasons for using the internet, DTL survey*

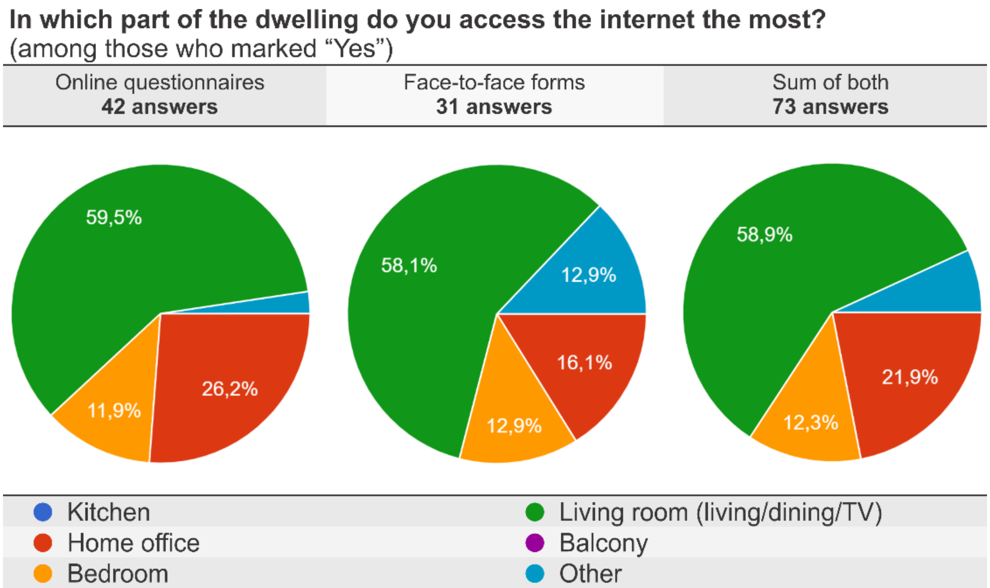

Figure 3.9 *Domestic space where the internet is most accessed, DTL survey*

The survey included questions that somehow investigated relevant points for the concept of aging in place, presented in "1.2.4 Aging in Place." Data from the survey sample confirmed trends already recorded by other authors, who claim that the desire to stay in their own dwellings is externalized by the vast majority among older adults (Coughlin, 2019, p. 36; Fonseca, 2018, p. 9; Lecovich, 2014, p. 21). In this survey, practically three-quarters of the sample (74.6%) asserted they had no desire to move to another home. When the question offered the hypothetical situation of staying in their own dwelling or going to a nursing home, the overwhelming majority (96.8%) affirmed they preferred to stay in their own dwelling (see *Figure 3.10*).

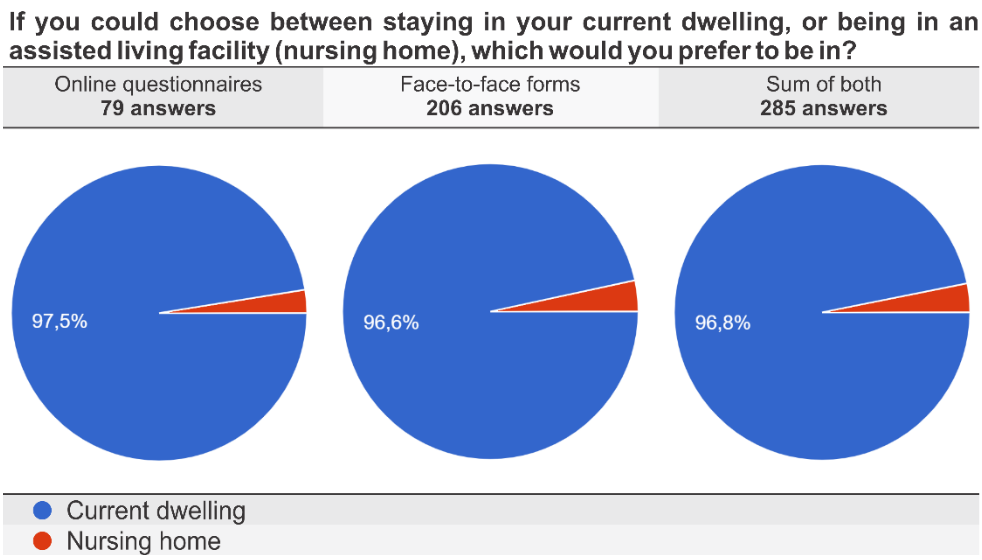

Figure 3.10 *Preferences of older adults regarding where to live, DTL survey*

The survey data also brings that most of the sample have lived in the same dwelling for a long time and probably have already established links with the place and its neighborhood, another point dear to the AiP concept. Also, according to the DTL survey, 80.4% of the sample stated that they have lived in the same dwelling for 10 years or more (this was the alternative with the longest time interval among the alternatives proposed by the survey). Nonetheless, in face-to-face forms, it was frequent participants voluntarily to state that they had lived in the same house for 40 or 50 years.

In summary, it is congruent to say that the DTL survey made it feasible to verify and draw a significant overview of older adults based on their sample. In addition to allowing the registration of some diversities, this panorama also enabled the recognition of certain predominance and trends. It is worth mentioning the prevalence of females, widowed people, and those who lived alone in this context. It was also evidenced that most of the sample spent their active time chiefly in the living room, lived in the same dwelling for a long time, and had no desire to move to another home. Television was the electronic device most significantly present and the most frequently used; however, other electronic devices also had a significant presence and frequency of use. Internet access and use were already a reality for a large part of the sample, which may help to demystify the possible notion that older adults are still oblivious to this type of technology. Although, the same data also confirms the existence of the mentioned digital exclusion.

The data provided by INE and the data collected through the DTL survey bring to the research a closer, current, and less stereotyped look at the domestic universe of older adults in Lisbon. Some behaviors and habits verified in the “Domesticity and Technology in Lisbon” survey, not yet discussed in this section, are discussed ahead, where the theme concerning *janelar* is addressed.

3.4 *Janelar*

This section addresses the habit of standing at the window and, based on this domestic specificity, investigates the development of some types of activity, whether practical, contemplative, or symbolic. This phenomenon can be verified in Lisbon and is commonly practiced by older adults, as shown through the data collected by this research, although this behavior is presumably to be repeated in many other locations and age strata. The two methodological instruments used were unsystematic observation, as proposed by Marconi and Lakatos (1985/2002, pp. 89–90), and the "Domesticity and Technology in Lisbon" survey, as mentioned earlier.

As already pointed out in the article "Towards a Digital Window" (Nogueira et al., 2020, p. 16), this habit is mentioned in the novel *O Primo Basílio* (1878/2009), by the renowned Portuguese Writer Eça de Queirós (1845–1900), which records its occurrence in Lisbon, still during the nineteenth century. Even if the register integrates a piece of fiction, it is reasonable to conjecture that it is, to some degree, a reflection of customs and traditions that characterized the city of Lisbon in the last half of the nineteenth century. The novel, originally published in 1878, mentions the *janelar*, as can be seen in the following passage: "E depois não tinha 'jeito', não sabia tirar partido das casas; via companheiras divertir-se, vizinhar, janelar, bisbilhotar, sair aos domingos às hortas e aos retiros"[84] (p. 77). *Figure 3.11* helps to illustrate how such a habit was architecturally contemplated within the domestic space in the eighteenth century. The image depicts the interior of the current "Galeria Zé dos Bois"[85] (ZDB), at the center of Lisbon.

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[84] "And she was no good at getting the best out of the houses where she worked: she saw her fellow servants having fun, making friends, watching from the window, gossiping, going out on Sundays to their allotments or to some quiet little nook somewhere […]." (Queirós, 1878/2011, Chapter III, p. 21, translated by Margaret Jull Costa)

[85] The building of the current gallery emerged as a dwelling, and according to information available on the very website of the cultural organization itself, it is a building from the second half of the eighteenth century, which was expanded in the nineteenth century (ZDB, n.d.). According to information on the ZDB webpage, D. Constança Emília Jaques de Vasconcelos e Meneses (1820–1896), Baronesa de Almeida, lived in this building, and between 1839 and 1840, lived the Writer Almeida Garrett (1799–1854), in its first floor (where the image in *Figure 3.11* was recorded).

In this context, the term used by Eça de Queirós (1878/2009) is taken here in its broadest way to characterize both the habit of staying at the window and the activities arising from this act (in addition to the more social and contemplative bias evidenced in *O Primo Basílio*). Among the possible activities, the research identified and investigated four main activities related to *janelar* in contemporary times: landscape contemplation and relaxation, social interaction, practical activities, and symbolic activities.

Figure 3.11 *The habit of standing at the window incorporated in the eighteenth-century building*

It should be noted that, depending on specific architectural factors, these activities are not exclusively performed at the window since those who have a backyard, a terrace, a balcony, or another architectonic element may, occasionally, execute some of these activities independently of the window. Nevertheless, as apartments (often without balconies) form a large part of the city's housing stock,[86] the activities carried out through the window become relevant in the context of Lisbon.

The unsystematic direct observations began in the second half of 2019 and continued until the first half of 2022. These observations made it possible to identify the four types of activities mentioned here. Due to their unsystematic nature, such observations happened spontaneously (Marconi & Lakatos, 1985/2002), as the phenomena were observed at different moments and locations in Lisbon. The photographic record was an essential instrument during this process, and a part of the material recorded is reproduced here in the panels that seek to illustrate the activities related to the *janelar* (see *Figure 3.12* and *Figure 3.13*).

The first panel (see *Figure 3.12*) contains images that present moments of landscape contemplation and relaxation, depicting moments of social interaction. Landscape contemplation and relaxation were usually seen as individual activities, although they may also happen in a shared way. Windows on higher floors can promote contemplation of the landscape, often favored by the rugged terrain of Lisbon, which frequently provides views with strong aesthetic appeal. As the nature of the activity suggests, social interaction takes place involving more than one person. In the records made during the observation, a person was usually located inside the house, and, through the window, they were able to interact with the person or people who were outside. Based on the records, it was found that this activity is more common among those who live on the ground floor due to the proximity to the street and the public promenade. It was also verified that some inhabitants have the habit of leaving small pillows at the window to avoid any discomfort during the time spent at the window (or pets can also stay comfortably at the window).

[86] As mentioned in the previous section, "3.3 Domesticity and Technology in Lisbon," 96.1% of the total sample of the DTL survey lived in apartments, for example.

Figure 3.12 *Various records capture the janelar throughout Lisbon in possible contemplation of the landscape and relaxation or social interaction*

Figure 3.13 *Various records capture practical activities and symbolic exposure in Lisbon*

The second panel brings records that quest to present activities of a practical and symbolic nature (see *Figure 3.13*). The more recurrent practical activities were the treatment of clothes by the window, especially their drying, which requires the inhabitant to stay at the window to spread them outside and then collect them. Caring for plants was also another form of practical activity registered. As to symbolic activities, several visual manifestations using the window space were captured, either from the planes that make up the window (generally composed of transparent glass surfaces) or through the window's opening, with flags or similar hanging from it. In both cases, the demonstrations were always externally oriented. Among the themes mostly recorded in this modality, expressions of a religious nature (generally related to Christmas festivities and specific saints) and the exhibition of the national flag stood out.

Based on the habit of standing at the window and the four activities perceived during the unsystematic observations, specific questions were designed regarding *janelar* in the DTL survey. The questions were inserted into "Section 3" of the survey, which investigates domestic relationships. According to the data obtained, 55.1% of the total sample claimed to have the habit of staying at the window, while 8.8% informed they would occasionally do it, and 36.1% said they did not have this habit.

Among those who answered that they were in the habit of staying at the window (even if occasionally), 95.4% chose "Contemplation and relaxation (enjoy the view/rest/smoking/etc.)" as the main reason to do so. "Social conviviality (greeting/waving/chatting)" was chosen by 50.3%, and 1.7% said they went for other reasons (it was possible to choose more than one alternative since it is reasonable to assume that people may have more than one reason to maintain such a habit). When asked about performing practical and symbolic activities by the window, 83.9% of this sample stated that they used it for "Practical Activities (drying clothes/shaking out rugs/taking care of plants/etc.)," 41.9% for "Symbolic activities (place the national flag, saints, etc./thematic decoration)," and 8.9% for other activities (here it was also possible to choose more than one alternative).

The data presented and the records of observations help to understand, albeit briefly, this domestic habit that has been present in Lisbon for a long time. In summary, it is possible to state that the survey data showed that more than half of the sample claimed to have the habit of staying at the window; among them, a large number used it to contemplate the landscape and relax besides carrying out practical activities. In a smaller proportion, but still displaying expressive figures, the activities of social interaction and symbolic demonstrations were also verified. The photographic records made during the research allowed to visualize, to some extent, all these activities. Conceptualizing and characterizing aspects of *janelar* in the context of Lisbon is an essential task because, as seen, the habit is present in the domesticity of most aged adults throughout the city and, precisely because of this, it becomes a significant influence on developments proposed in the next chapter.

3.5 Conclusion

This chapter presented and related quantitative and qualitative data from different sources about the phenomenon of population aging in the city of Lisbon. The information allowed a better understanding about the dimension of this phenomenon, and some particularities related to domesticity and the use of information technologies by the stratum of older adults.

In “Population Aging in Lisbon” (3.2), the documentary sources published by INE (2021a, 2021b), especially the “Censos 2021,” provided population data for the year 2021, which recorded an evolution regarding the aging phenomenon both in Lisbon as in its metropolitan area. The data pointed to an increase in the proportion of older adults within the AML and stability when the city of Lisbon is observed in isolation, where older adults already represent practically a quarter of the total population. It was also verified that the aging index continues to rise and that there is a numerical predominance of the female gender in the cohort of people aged 65 and over in Lisbon.

In “Domesticity and Technology in Lisbon” (3.3), specific material from “IUTICF – 2020,” provided by INE, indicated that most of the population aged 65–74 years old residing in AML lived in a dwelling having internet access. The same document stated that almost 60% of this age group had used the internet within the three months prior to the survey. In the inquiry “Domesticity and Technology in Lisbon,” conducted through this research, the proportion of internet users among those who had internet access corresponded to half of the sample, evidencing both the dissemination of online connection and the digital exclusion as regards this group. This same survey sought to present an overview as to older adults, addressing some domestic relationships and information technology. Based on the sample of the DTL survey, it was possible to notice, in general, the participation of Portuguese people living in apartments, primarily female, widows. They spent a significant part of their active daily time inside the dwelling, especially in the living room, where they used many of their electronic devices, predominately television and cell phones. Overall, they expressed no desire to move to another home, the wide majority preferring to remain in their own homes rather than moving to a nursing home.

In “*Janelar*” (3.4), the habit of staying at the window was investigated and characterized. The research initially resorted to unsystematic observations in Lisbon, where four main activities developed through this domestic habit were perceived: contemplation of the landscape and relaxation, practical activities, social interaction, and symbolic activities. Subsequently, the DTL survey provided information that made it possible to verify the occurrence of these activities, with a predominance of landscape contemplation and relaxation besides practical activities. Nevertheless, all four types of activities were relatively frequent within the survey sample. Understanding the *janelar* in the domesticity of older adults in Lisbon is an important contextual element for the developments proposed in the next chapter.

All the data recorded in this chapter pursued to format a portrait of population aging, domestic habits, and relations with information technology in the Lisbon context. Starting from recognizing this panorama, it becomes feasible to envision architectural alternatives that may emerge from the intersection between this context and the digital window concept, precisely what guides part of the developments proposed in “Chapter 4 - Digital Window System.”

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Digital Window System

[chapter]

4

Digital Window System

This chapter presents the development of a system based on the digital window concept—the Digital Window System (DWS)—seeking to provide the inhabitant with new ways of experiencing domestic space and digital information. Initially, it is intended to define the system and relate the themes already dealt with in previous chapters, which served as premises for developing the DWS. Next, AI is presented as a relevant interaction tool for the DWS through machine learning techniques, especially methods used for natural language processing and computer vision. Finally, the prototypical development of the DWS apparatus is presented, emphasizing the elaboration of its dynamic components and the Digital Window App (DWA).

4.1 Introduction

Starting from the digital window concept proposed in Chapter 2, this chapter presents the development of a system capable of supporting such a metaphorical architectural element. The system developed here aims to allow the integration of digital information with the built space, in a manner coordinated by the inhabitant and for their benefit. However, it is relevant to keep in mind that the digital window concept is not restricted to this proposed system, as it can potentially be contemplated by other setup that explore similar premises to this research.

Therefore, the DWS shares the general hypothesis of this research that it is possible to enhance the qualities of the architectural space through digital information, especially in the domestic context, which is the focus of this work. Thus, the developments recorded within this chapter aim to enable interaction among inhabitant, built space, and digital information, providing means to test the system, pursuing to validate the hypothesis, which will be dealt with in Chapter 5.

In general, it is possible to affirm that the DWS emerges from intertwining a series of questions that have permeated and constituted this research. Chapter 1 brought aspects regarding domesticity, ways of living, and contemporary population aging that underlie part of the proposal, while discussions about cybernetics establish the grounds for this type of systemic approach in architecture. Chapter 2 theoretically structured the digital window concept, which is the basis for the design of the DWS, also presenting works of a related nature, which serve as general inspiration for the design of the system. Finally, Chapter 3 allowed to observe, understand, and verify characteristics referring to older adults in the context of Lisbon, outlining guidelines and fundamental functionalities for the development of the DWS.

One of the main goals of this section is to present the development process of the prototype of the DWS apparatus. According to Saenz and Valencia (2012), this prototype can be methodologically considered a high-fidelity prototype, as it is characterized as a prototype of great likelihood, developed to be tested, aiming at its evaluation (p. 482). In order to record the design and development of the different dimensions of the DWS, this chapter continues through the following topics:

a) “DWS Fundamentals” (4.2): quests to define the system besides describing its main goals. This section also brings together topics and data presented in previous chapters, which are understood as premises that determined the structuring guidelines on the DWS design process. Finally, aspects concerning the system interface and modes of interaction are discussed.

b) “AI and DWS” (4.3): deepens the understanding concerning the AI approach, started in “1.3.4 Artificial Intelligence,” introducing the concept of machine learning, its main methods, and some of its applications, notably in natural language processing and computer vision. This deepening is necessary for the scope of this research because these methods are introduced in the DWS as relevant tools to the interaction process involving humans and machines.

c) “Developing the DWS” (4.4): briefly reports the main dimensions, components, and characteristics regarding the development of the DWS apparatus. The system is described in its physical dimension (electronic components used, modeling and digital fabrication of support parts, assembly, preliminary tests, and adjustments) and in its abstract dimension (application development, programming in blocks, preliminary tests, and critical points). Therefore, this section presents the development of the dynamic components and the DWA that constitute the prototypical version of the DWS apparatus.

The sequence of topics dealt with in this chapter, additionally to detailing the elaboration of the DWS as a device with domestic implications, also pursues to highlight and contextualize important guidelines for its conception as an architectural system. This system aims to provide the inhabitant with the means to experience new relationships within the built space and digital information through the digital window concept. This process leads to the development of the DWS prototype, enabling the establishment of such relationships for the benefit of the inhabitant, and the realization of the test to validate the research hypothesis presented in the next chapter.

4.2 DWS Fundamentals

4.2.1 Understanding the DWS

DWS emerges as the proposition of a system capable of supporting the digital window concept. Therefore, the DWS can be understood as an architectural system capable of configuring a metaphorical window based on visualizing digital information. In the context of the possibilities offered by the DWS apparatus, the metaphorical architectural element results from the projection of said digital information on the surfaces of the built space through a dynamic relationship coordinated by the inhabitant.

The relationship between built space and digital information, more generally, is a research path that quests to reflect on and explore impacts in architecture arising from advances in computing in a broad sense and the popularization of the internet in recent decades.[87] This approach, in the scope of this research, is an offshoot of issues already discussed in "2.2 Like a Second Sort of Body." Thus, perceiving the blurring of dualities identified in contemporary times (Colomina, 1994; Diller & Scofidio, 1994; Teyssot, 1994, 2005; Tramontano, 1998; Vidler, 1992), the emerging relations among body, space, and prosthesis defended by Teyssot (1994, 2005), besides implications of technological culture on the perception of materiality proposed by Picon (2003, 2016), are vital points for the development of the DWS.

Accordingly, the DWS is proposed as an architectural prosthesis capable of extending the body's capabilities by mediating its relationship with digital information and the space that houses it. Such space, having its visual qualities partially altered by the DWS, enables the inhabitant to visually explore new materialities (and functionalities), enhancing their experience. Furthermore, altering the qualities of a surface that receives the digital window—in the fraction of time and space in which the phenomenon takes place— deepens the blurring in respect to the surface (wall) opacity and

[87] Even though they configure different proposals among themselves, also in relation to the DWS, projects such as *ADA*, *Media House*, and even FPC's *House of the Future*, among others, are born from this same prism.

porosity, as previously discussed by Bragança de Miranda (2006), Colomina (1994, 2006, 2019), and Friedberg (2006), in comparable contexts.

From the perspective of cybernetic theory (treated in Chapter 1), the DWS can be understood, in general, as a second-order system since the proposed setup brings together the observer and the observed systems in the same system (von Foerster, 1979/2003b). In this approach, an architect initiates a second-order cybernetic process where the professional observes and arranges (or rearranges, depending on the context) the architectural and informational systems. Then, in a second moment, the inhabitant becomes the observer of the second-order system, operating the exchange of information according to their needs and possibilities it offers.

The main goal of the DWS is to expand the possibilities offered by the architectural space through its relationship with digital information to favor the inhabitant. In principle, there are already many devices and systems that, in some way, partially contemplate this objective. A room equipped with a computer can already offer means of accessing digital information in domesticity, for example. However, in commonplace examples like this one, a frequent indifference to spatiality is perceptible, which, in architectural terms, is quite critical and highlights a gap that efforts such as the DWS intend to fill.

The DWS targets precisely at taking advantage of architectural spatiality as a means of integration with visual information (see *Figure 4.1*). Consequently, the inhabitants have at their disposal a device that allows them to “open windows” on the opaque surface of the wall, temporarily altering its materiality and function. On the other hand, it is also reasonable to envision new possibilities and functions when digital information has the architectural space as its support, not being restricted only to objects/devices.[88]

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[88] As a matter of focus, this research does not delve into the topic of digital possibilities that can arise when space is understood as its support. However, in principle, the approach that seeks to expand spatial qualities through digital information does not cancel out the expansion of possibilities of the digital medium that appropriates the architectural space as its support. Therefore, other works that aim to further investigate the relationships between computer science and architecture can explore these relationships.

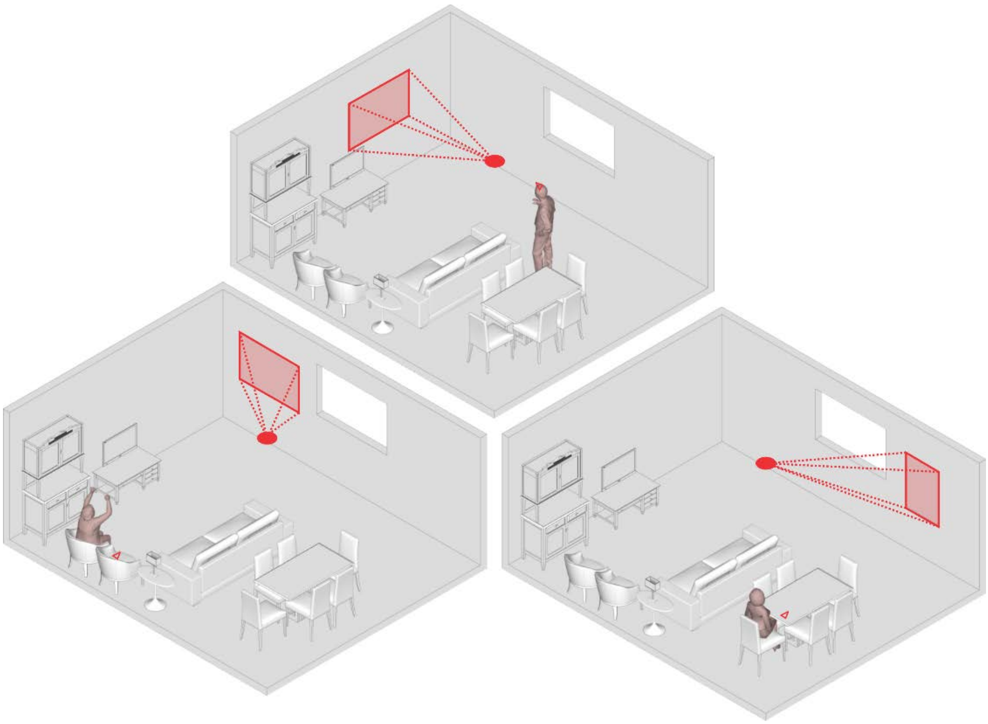

Figure 4.1 *DWS and the architectonic spatiality*

By another analysis bias, the DWS can be considered a device that operates within the concept of augmented reality (AR), according to the definition of Computer Scientist Ronald Azuma (1997). For Azuma, *augmented reality* is a variation of virtual reality (VR). While VR presupposes immersion in a completely virtual world, in augmented reality the real world remains the main space for viewing and referencing, but it is mixed with fragments of the virtual world.[89] In this sense, it is possible to understand the DWS as a space hybridization system, according to what Teyssot (2005) proposes in "Hybrid Architecture: An Environment for the Prosthetic Body."

Given the above and in synthesis, the DWS apparatus can be understood as an architectural prosthesis based on a second-order cybernetic process, exploring augmented reality and generating a hybrid space in the domestic environment. Once identified in this way, it becomes relevant to understand and structure the main points that constitute the DWS proposal, its premises, particularities, functionalities, and mode of operation.

[89] The terms "real world" and "virtual world" are used in the sense expressed by Azuma (1997) in the article "A Survey of Augmented Reality." Regarding the term "virtual," the meaning used by Azuma partially diverges from the meaning expressed by Friedberg (2006), discussed in footnote 47, and by Lévy (1998, p. 23).

4.2.2 Composing the DWS

In essence, the DWS, as described so far, is a system that relates architectural spatiality and digital information in a user-coordinated manner. This proposition shows a wide range of solutions that, hypothetically, can be developed from this systemic approach proposed by the DWS. Within the hypothesis defended in this research, several needs and specificities that architecture deals with can potentially benefit from this approach.[90] This type of system can, for example, be applied in schools as an element of pedagogical support in classrooms, at home as a personal visual assistant, and in commercial spaces as an interactive digital showcase, among many other options that may be envisioned.

However, due to the research scope, it is necessary to define more precisely the range of the system version developed here. Therefore, in this work, the DWS focuses on the domestic space and older adults (in the context of Lisbon), modeling digital information to cover functionalities developed from such setting. Consequently, this section is intended to list the main demands, limits, motivations, and inspirations, which serve as a starting point for elaborating the DWS.

Among the vast repertoire of spatialities produced by architecture, the choice of domestic space as an area of action for the DWS follows the logic established by Gonçalo Furtado and Inês Moreira (2001). The authors point to the house as the most recurrent demand of architecture, with which people relate more directly and for a longer time, considering it a kind of contemporaneity barometer, as mentioned in the "Introduction" of this thesis.

Amid the various questions posed in Chapter 1 about the contemporary way of living, the issue of population aging sticks out, especially in the Portuguese and Lisbon context. This fact is attested through the data provided by INE (2020a, 2020b, 2021a, 2021b), reproduced in Chapter 1 and

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[90] The article "Domesticity and Artificial Intelligence: Toward New Design Approaches" (Nogueira & Romão, 2021), presented at the 10th PROJETAR, in 2021, cited in "g. Academic Developments," and included in "Appendix E," deals with issues related to this approach.

Chapter 3. This finding justifies the election of this stratum of the population as the focus of action for the DWS.

However, in this research, it is considered that older adults and other age groups face a wide range of critical issues in contemporary times, whether economic, social, emotional, health-related, concerning mobility, among many other variants. Some of these issues can eventually be resolved or alleviated with interventions related to architecture and domesticity, primarily when supported by concepts such as aging in place. Nevertheless, it is relevant to realize that older adults also face other issues alien to architecture, therefore not being within the range of this work.

Hence, the DWS has its performance designed to meet some demands of older adults. Within that, the performance system is limited to its domestic universe and issues related to digital information. It is noteworthy to note that access to digital information often remains a challenge for many older adults since a considerable number among them were not educated in digital media (generally, they were not available to the public when they attended school) or had not inserted it into their work environment, besides other reasons. This situation generates the phenomenon of digital exclusion, discussed in "1.2.4 Aging in Place" (and, to some extent, verified by the DTL survey as described in Chapter 3). Digital exclusion is a contemporary problem, often intensifying the isolation of older adults or hindering their access to goods and services in a society increasingly digitized and automated.[91] It is worth noting that Negroponte (1995) had already foreseen this digitization of society in the last decade of the twentieth century.

The DWS is proposed as an architectural device intended to enable digital inclusion, simultaneously functioning as an agent that facilitates access to those already digitally included. It is relevant to remember that

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[91] The health crisis that broke out in 2020, generated by the COVID-19 pandemic, abruptly intensified the need for digitalization of communication, which became a problem particularly felt by older adults. Unfortunately, concurrent to the fact that this is a portion of the population showing a considerable degree of digital exclusion, this group was also one of the groups most encouraged to practice social isolation because it is understood as a portion more vulnerable to infection. According to testimonies provided by both SCML users and employees during the application of the DTL survey, this combination of factors, among other things, had an impact on depression, social phobia, and severe isolation.

digital inclusion can help improve the overall health quality of older adults (Betts et al., 2019) and provide them a more active life (Guimarães, 2021). Consequently, the DWS can enhance the quality of time that older adults spend at home, favoring the AiP concept. In this context, it is also worth remembering that the domestic space is where older adults spend most of their time (Burton et al., 2011), which, to some extent, was also verified by the DTL survey.

Broadly, the DWS can be inserted into—hypothetically—any domestic space.[92] However, the system was designed to have the living room as its referential space. This choice is justified because this is the domestic space where the DTL survey sample declared to spend most of their active time. Moreover, it was the space that already housed most domestic information equipment (television, cell phone, tablet, landline) and where their use was most frequent.

Based on information from unsystematic observations conducted in Lisbon, and the DTL survey, both already discussed in Chapter 3, the DWS has its functionalities partially inspired by the *janelar*. Consequently, its algorithm was designed to attempt, at some level, to incorporate habits already established inherent to a portion of this population. This strategy quests, initially, to take advantage of the simple analogy that can be established between the conventional window (and activities performed along with it) and the metaphorical digital window (besides the functions it may play).

The activities verified and described in "3.4 *Janelar*" are not reproduced literally since each element—conventional window and digital window—has its particularities, potential, and limitations. Nonetheless, some parallels can be drawn. Taking landscape contemplation and relaxation as a starting point, the DWS offers the possibility of connecting to cameras that produce live images from different views, from different points of the city, or even from other cities.

[92] In general, it is possible to say that the DWS is not suitable for bathrooms, and balconies due to their limitations besides spatial and functional characteristics of these spaces.

Accordingly, the DWS can be understood as an architectural prosthesis that, in a way, expands the range of vision since it provides images that were not previously possible to be seen in the same way. However, within this research scope, it is not possible to affirm that these transmitted images will have the same contemplative or relaxing power as an analogical view does. On the other hand, it is undeniable that, like the analog view, the digital reproduction of landscapes in real-time can transmit information about the weather, other aspects of the day, and what is happening in certain exteriority, among other possibilities.

Regarding social interaction, the DWS provides the possibility of making video calls that allow the exchange of sound and image in real-time between people in different locations to simulate a possible dialogue that occasionally may be established next to the window. This function is a feature that is already quite common in many applications, especially on smartphones. Nevertheless, the DWS, as it integrates architectural spatiality, can offer a broadly generous screen dimension, which often allows the image of the person being spoken to be closer to natural size, avoiding the miniaturization perceived in smartphones. Moreover, if one considers that vision problems tend to become more common or intensified as age advances, the miniaturization offered by most current media can be overcome by the DWS spatial approach.

Still, concerning the possibilities of contact that the social interaction close to the window can offer, in the same way, that more than two people can participate in a conversation by the *janelar*, the DWS allows more than two people to participate in the video call. It can happen because more than one person can be making or answering the call and the system enables the inclusion of more than one contact on the same call.

Concerning practical activities, such as drying clothes or taking care of plants, the analogy involving what is done next to the conventional window and what can be done in the digital one is more complex. The video call function could even be understood as a possibility of carrying out practical activities since it is part of the professional activity of many workers (such as online meetings); however, this is not the expected behavior within this stratum of the population, which, for its most part, is already retired.

Given the above, practical activities were replaced by entertainment activities, such as “watching television” (online live broadcast of television channels) or allowing access to the internet (search and video platforms). According to the DTL survey data, the sample showed that they spend significant time watching television. Additionally, among those who already used the internet, many did so to find entertainment. This information justifies the insertion of a window dedicated to this type of activity.

As for the symbolic activities, where people use the window to express aspects of their culture, the DWS can offer a wide range of images that correspond to the main symbols noticed in the windows of Lisbon (Christmas themes, national identity, and related to the “25 de Abril”). However, here there is a significant difference: while the conventional window allows the display of symbols to the outside, the digital window makes viable to characterize the internal space (or to complement this eventual characterization). In short, it is possible to understand this functionality in a relatively similar way to the effect produced by the insertion of a “Christmas tree” in the internal ambiance, that is, as a symbolic element used on a specific occasion to add a unique character to a particular domestic space (generally the living room). In addition to the symbolic themes, the possibility of presenting personal images was also added to the DWS, functioning as a digital picture frame or an electronic memory extension prosthesis. This latter can be understood as an illustrative example of electronic memory proposed by McLuhan (1964/1994, p. 3; see footnote 33 and 66).

Since the DWS purpose is not—by any means—to replace conventional windows, it is not problematic that the functions offered by it do not present precisely the same possibilities of use and interaction as those allowed by conventional windows. Nevertheless, the DWS objective is to incorporate certain qualities already offered by conventional windows and to appropriate uses and habits already established, taking advantage of how some people use their window, in a bottom-up approach. In this context, it would be expected that, in a hypothetical everyday use of the DWS, people would develop new relationships with the digital window based on the functionalities proposed, some closer to the habits that they occasionally perform close to the conventional window and others particular to the digital element. In this hypothetical logic, the relationship that users would develop with the digital window would be a rich analysis material for its constant evolution and updating.

As a matter of safety and agility in requesting help, the DWS also provides a more straightforward means of triggering medical emergencies. Therefore, the emergency telephone contact was incorporated into the system's algorithm, along with commands that authorize an emergency call upon request. Such a procedure can be processed independently of any of the previous uses that may be performed.

Generally, it is not possible to state that the DWS was developed to meet the needs of widowed older adult women preferentially; a pattern frequently observed in this population cohort, as evidenced previously. Nevertheless, it is possible to state that this niche is well represented in the data—official and from the DTL survey—that helped compose the DWS. Therefore, the premises that drive the development of the system are, to a large extent, a reflection of this significant profile.

As some guidelines and strategies for the DWS have already been outlined, it is now possible to go back to the related works presented in Chapter 2 and see, briefly, how they influenced the design of the DWS. Regarding the projects presented in "2.4.1 Architectural Narratives," FPC's *House of the Future* demonstrated the possibility of developing a systemic approach permeated by digital information in the domestic context. The *Philips Pavilion*, by Le Corbusier and Xenakis, inspires how visual information appropriates architectural spatiality. Finally, the capture and transmission of a view beyond that spontaneously present in the site have as reference the device created in the *Slow House* project by Diller and Scofidio.

In "2.4.2 Cinematographic Narratives," the works presented have inspired the DWS in different ways. The "history picture" of *Things to Come* (Menzies, 1936) illustrates, from a very early age, how a screen capable of presenting varied visual information can be metaphorically equated with a window. The set of devices that enable the formation of the “wall screen” in *Minority Report* (Spielberg, 2002) allows envisioning how digital information can be incorporated into the domestic space and how functionalities can emerge from this context. The spatial freedom that the apparatus presented in *Blade Runner 2049* (Villeneuve, 2017) attributes to digital information in the domestic space and the means of interaction based on AI techniques are relevant references to the design of the DWS apparatus. However, it is important to safeguard a distance between these sci-fi works and the development of the DWS, which is inspired by these possibilities illustrated by cinematic fantasy but has neither the aim nor the belief of reproducing them literally.

Broadly, this section has listed central facts, justifications, motivations, and inspirations for the approach proposed by the DWS. Both the concepts discussed in Chapter 1 and Chapter 2, as well as the data presented in Chapter 3, underpin the developments proposed in this fourth chapter. Subsequently, the DWS is approached from the point of view of interface and interaction, relevant points for the system functioning, and determining how it relates to the inhabitant, allowing its control through different manners.

4.2.3 Interface and Interaction

Some points that differentiate the DWS from the simple existence of a device for accessing digital information in the domestic space are the modes of interaction that it operates and the interfaces developed to support these different means of exchanging information. In this context, *interaction* is defined as the exchange of information between two systems, which can be carried out between humans, between machines, and between humans and machines (Haque, 2006), as is the case for the DWS (described in detail in “4.4 Developing the DWS”). Complementarily, the author Steven Johnson (1997), defines *interface* as the system resources that shape this interaction.[93] Often the interfaces that mediate the relationship between user and

[93] According to Johnson (1997), the development of computer graphical interfaces was accompanied by several architectural metaphors. The popularization of terms such as “window” and “desktop,” as well as “chat rooms,” exemplify this recurrence. Other less successful proposals also sought to use spatial metaphors such as *Bob*’s “family room” (a Microsoft software package, released in 1995,

computer systems resort to graphic resources, then called Graphical User Interface (GUI).

The history of interface development in computing and its importance for the popularization and domestication of computers, especially in the second half of the twentieth century, are well-documented processes. Books such as *Interface Culture* (Johnson, 1997), *Being Digital* (Negroponte, 1995) and even *The Virtual Window* (Friedberg, 2006) describe in detail the main events, personalities, and developments in the field of the graphical interface.

Accordingly, it is possible to briefly highlight the doctoral thesis defended in 1963, at MIT, by Ivan Sutherland, about Sketchpad, introducing interactive graphic objects to the computer (Negroponte, 1995, p. 103). In 1968 took place the famous 90-minute presentation at the Fall Joint Computer Conference in San Francisco (Friedberg, 2006, p. 224), in which Douglas Engelbart[94] (1925–2013) came to be considered the father to the modern graphic interface (Johnson, 1997, p. 14). During the 1970s, the team at Xerox PARC made significant advances (Johnson, 1997, pp. 15–16). After Steve Jobs visited Xerox PARC in 1979, his company launched the Macintosh in 1984, a computer with an interface that prioritized graphics over command lines, consolidating the graphical approach ever since (Friedberg, 2006, p. 224).

The graphical interface continues to be an essential aspect for the DWS operation, mainly through icons, buttons, texts, images, and video boxes. Though, DWS also has a voice-command interface, which allows for speech interaction, the system being able to "talk" and "listen" (using NLP

shortly before the release of the *Windows 95* operational system), or the rooms of *The Palace* software, by Mark Jeffries, among others.

[94] Engelbart also introduced the mouse, a tool that played a crucial role in the domestication of the computer (Johnson, 1997). Picon (2003) and Wigley (2010) address the importance of the mouse as a prosthesis that allows more direct interaction between the user and the digital content and point out to the importance of the mouse as a facilitating tool in the digitization of graphic representation in architecture, together with software of Computer-Aided Design (CAD).

tools). In a way, it is still reasonable to say that the system has a spatial interface because when it is started, it travels through all the space surfaces (with a 360º turn leftward and another to the right). This path makes it evident that the visual content can be displayed in horizontal (landscape) as well as in vertical (portrait) position,[95] even enabling the user to change the screen location whenever they want. Thus, it is possible to affirm that the DWS approaches a multimodal interface, as proposed by Negroponte (1995, p. 99).

In the graphical interface of the DWS, the clarity and simplicity of its design, intense contrasts (generally black, white, and red), large fonts, and the concomitant use of numbers, texts, and icons were prioritized. These choices are the strategies to ease identification of the system parts by a greater diversity of users, including people who are illiterate or with some degree of vision impairment. The DWS home menu organizes its four main functions (referring to *janelar*) into four specific and highlighted windows, displaying icons for the interaction and emergency channels (which are repeated in all available windows).

Most windows related to *janelar* also offer four different content options. This repetition is intentional and aims at generating familiarity among the different parts of the DWS. The visual language developed is relatively sober, avoiding the creation of a proposal that refers to infantilization or stereotyping of the target audience. In the context of product and technology development design targeting older adults, Coughlin (2019) states that stereotyping this audience tends to alienate them and reveals ignorance regarding their preferences (p. 33).

The voice interface advocates simple dialogues, favoring objective and direct responses, following the observations of Russel and Norvig

[95] The format flexibility offered by the DWS would have been a curious component in the context of the controversy regarding vertical and horizontal windows, which began in the early 1920s in France. While Le Corbusier introduced the horizontal windows (strip window), Auguste Perret (1874–1954) made an unrestricted defense of the vertical windows (also known as the French window), as discussed in the article "'Une Petit Maison' on Lake Leman: The Perret-Le Corbusier Controversy" (Reichlin, 1988).

(2010, p. 917). The system has been programmed to recognize a relatively wide set of words that allow certain functions to be performed and prevent it from being inflexible or overly restrictive. For example, if the goal is to access “Window 1,” the user might say “window 1,” but the system will also accept commands like “one,” “first,” and “see through,” among others.

The spatial interface aims to illustrate the possibilities of use and positioning by adapting the screen format content displayed (see *Figure 4.1*). Thus, the initial turns show the user that the screen can be placed on any part of the surfaces covered by the projection. Additionally, the system automatically changes the horizontal and vertical layout according to the type of content and function being executed.

As for interaction, it manifests itself in two complementary ways in the DWS. Accordingly, there is a dynamic-spatial interaction and an operational-functional interaction. Even though the DWS features this dual interactive system, where each subsystem handles information of quite different natures and aggregate of these generates a whole with a certain degree of complexity, interactive systems, when analyzed in isolation, can be considered a relatively simple system. According to the classification proposed by Haque (2006), these subsystems operate by “single-loop interaction.” On this wise, the systems generate actions directly related to the information received in a direct and closed cycle. Therefore, certain types of information the system obtains, such as body position (or movement), a spoken word, a gesture, or a touch, trigger responses predetermined by the DWS algorithm.

The dynamic-spatial interaction is the resource that allows integrating digital visual information with the architectural space. Through such interaction, the DWS has mechanisms that mechanically let the system to change its position according to the inhabitant’s desire. This device permits digital information to occupy different positions in the vertical planes that delimit the internal space, effortlessly adapting to different daily routines and activities that the inhabitant usually performs. In principle, the system was designed so that the mechanical device dynamically responds to the positioning of the inhabitant's head, keeping the digital information perpendicular to the user's gaze. However, during the test (which will be presented in Chapter 5), for reasons of system sensitivity, the device was operated as a type of remote control, where the user manipulates the issuer control to adjust the position of the DWS, as they please.

The operational-functional interaction concerns the three interaction paths to access the windows provided by the DWS and other adjacent functionalities (such as triggering the emergency call). In general, it is possible to affirm that practically all the main windows and functions can be accessed by all three types of interaction, namely: by (1) touch, (2) speech, and (3) gesture. Moreover, it is worth mentioning that these three paths have become increasingly widespread with the popularization of touchscreens and with the development of AI-based interfaces (further explored in "4.3 AI and the DWS"). Briefly, these three means of interaction operate as follows:

1) Touch: based on the options visible through the graphical interface (images, icons, and texts), the user selects by touching the sensitive screen.[96] This interaction resource authorizes the user to perform all the primary activities, that is, choose windows, open and close them, in addition to returning to the initial menu or activating the emergency call.

2) Speech: using AI mechanisms related to natural language processing, the system uses speech recognition techniques to distinguish the words spoken by the user (when requested). Once the beeps match the words fed to the system algorithm, the DWS executes them. Thus, it is possible to perform all the essential activities described in the previous item through voice interaction.

[96] Among the interaction options, the touch, due to the ease of dealing with external systems which the DWS uses, is the means of interaction that allows performing more specific functions, such as pausing a video being played via streaming, for example. However, in general, all three types of interaction manage to equally perform all the tasks described as primary.

3) Gesture: through image recognition,[97] allowed by computer vision mechanisms, the system can statistically distinguish some manual gestures (such as a closed hand or raised fingers, for example). These gestures are converted into labels, and the DWS algorithm associates these labels with specific actions, enabling this interaction method to perform all the primary activities.

Essentially, these are the interactive approaches that the DWS interface brings about to the inhabitant to coordinate the relationship between architectural space and digital information, mediating this exchange of information. Subsequently, more specific aspects of ML and their implications for NLP and computer vision are addressed, attempting to elucidate how these methods operate and how they help the DWS to "speak," "hear," and "see" the inhabitant. Finally, once these methods are assimilated, it is possible to approach the development of the DWS in its entirety ("4.4 Developing the DWS"), exploring the relationship between the support devices added to the system and the parts developed especially for the functioning of the DWS.

[97] This image recognition follows the same initial protocol and apparatus used to create the *room_ID* application, discussed in the article "*room_ID*: An Architectonic Image Classifier Tool Correlating Machine Learning and the Domestic Space," (Nogueira & Romão, 2022), mentioned in "g. Academic Developments," and presented in the "Appendix G."

4.3 AI and the DWS

4.3.1 Machine Learning

In addition to the general approach regarding AI presented in Chapter 1, it is necessary to delve deeper into NLP and computer vision, as they are fields of AI that provide two important means of interaction between the DWS and the inhabitant, as mentioned in the previous section. Moreover, both NLP and computer vision are fields of AI that have taken advantage of machine learning techniques to improve their functions. Therefore, this section seeks, briefly, to introduce ML and its main learning methods.

Given the influence that ML currently exerts on AI and its implications in other subfields, it is relevant to understand some of its concepts and methods. In general, Helder Coelho (1996) states that *learning* is sometimes based on criteria of simplicity and, therefore, focuses on finding a simple description of reality (p. 95). In this context, simplicity and abstraction become fundamental elements for information treatment when building learning algorithms.

Accordingly, from a ML algorithm is expected that its instructions allow it to learn from its experience (Oliveira, 2017, p. 7). Three strategies stand out in this objective: unsupervised, supervised, and reinforcement learning (Russell & Norvig, 2010). In *unsupervised learning*, no feedback or explicit labels are provided; the algorithm finds patterns among the inputs available. In *supervised learning*, examples of inputs and expected outputs are provided, which enables the algorithm to map patterns between what is provided and what is expected as an output, creating a function based on this relationship (a model commonly used in recognition image, for example). In *reinforcement learning*, rewards and punishments about a given objective shape the algorithm learning in a dynamic environment. Furthermore, there is still *semi-supervised learning*, where only a few examples are offered, even in the face of a large amount of data, mixing both supervised and unsupervised approaches (pp. 694–695).

Within these approaches, there is a wide range of concepts, strategies, and mechanisms allowing ML to adapt to different situations and needs, such as neural networks, decision trees, regression, linear regression, univariate and multivariate linear regression, learning curve, Kernel methods, Ockham's razor, among many others (Russell & Norvig, 2010). As a matter of theoretical framework, historical relevance, and implication in the subfields of NLP and computer vision (addressed in the following item "4.3.2 Speech and Vision"), this research will focus on understanding artificial neural networks.[98]

Neural networks are computational models based on interconnected structures of simple neuron models, with the ability to compute input values. It is inspired by biological neural networks; however, they do not aim to be a faithful copy of the neuron, only using it as a reference for abstraction (Oliveira, 2017, p. 107). Russell and Norvig (2010) summarize it by stating that "a neural network is just a collection of units connected together; the properties of the network are determined by its topology and the properties of the 'neurons'" (p. 728). Alternatively, in a way more akin to computer science, it can be said that neural networks represent complex nonlinear functions with a network of linear boundary units (p. 758).

Neural networks—since perceptrons—have drawn the attention of both AI researchers and statisticians.[99] Such interest stems from their more abstract properties, enabling the realization of distributed computing, dealing with noisy inputs, and the ability to learn. Even if other types of systems, such as Bayesian networks, also have these capabilities, neural networks remain efficient and widely used (Russell & Norvig, 2010).

Perceptrons are simple neural networks, developed by Frank Rosenblatt (1928–1971) in 1957 (Russell & Norvig, 2010, p. 761). For Oliveira (2017), perceptrons aroused interest for two main reasons: first, because of

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[98] In this text, these will be called only by the term "neural networks" (NN), as many authors in AI do. Therefore, due to the general thematic of this work, it is not expected to conflict with the term used in biological sciences.

[99] Books such as *The Elements of Statistical Learning: Data Mining, Inference, and Prediction* (Hastie et al., 2009), show how statistical approaches are fundamental in the learning models used in ML. Both areas have complemented each other in recent decades.

the already mentioned similarity (in some senses) with the generic behavior of biological neurons in their way of reacting to inputs; second, because this algorithm corresponds to a simple mathematical rule, capable of adapting the input weights according to the accomplishment of the desired task (p. 105).

Also, according to Oliveira (2017), many different techniques are created to adjust the weights that interconnect the simple units of a neural network, modeling its learning. An example is the algorithms with the back-propagation technique, which work in the perceptrons. Furthermore, a wide variety of other techniques and models have been continuously developed, including algorithms that considerably expand the range of applicability of neural networks. This evolution is due to large amounts of training data, the application of sophisticated multilayer architectures, and “various neuron models to derive complex structures that include intermediate representations of complex attributes” (p. 110). Lately, this approach has more recently been called *deep learning*. In addition to using standard connectionist techniques (such as back-propagation), also seeks support in neuroscience and patterns observed in biological nervous systems (p. 110).

Given all the advances and the predominance of ML in AI, especially in the last decade, Scientist Gary Marcus (2020) argues that, for the next decade, it will be necessary to go beyond ML, but without denying it; nevertheless, expanding its approach, toward what the author calls Robust AI. To this end, Marcus (2020) suggests a paradigm shift where he proposes four essential cognitive prerequisites: A hybrid architecture[100] able to combine (a) large-scale learning with (b) the abstraction and computational capacity intrinsic to symbol-manipulation; also, (c) large-scale knowledge bases, and (d) sophisticated cognitive models, capable of simultaneously dealing with these mechanisms and knowledge bases (Marcus, 2020).

The concepts and methods of ML presented here, despite very briefly, are essential for a general understanding about the mechanisms that

[100] Gary Marcus (2020) refers to the term “hybrid architecture” in the context of Computing, referring to the architecture of electronic systems. He defends an approach capable of mixing different computational architectures that have been important in developing AI.

enable computers to learn and their types of learning. Moreover, these concepts and methods are basal to a wide variety of applications emerging through this learning in the other subfields of AI and are already quite widespread. As with the machine learning engine employed in the DWS interaction mechanisms based on NLP and computer vision.

4.3.2 Speech and Vision

Among the six main subfields of AI—automated reasoning, computer vision, knowledge representation, machine learning, natural language processing, and robotics—listed by Russell and Norvig (2010), two are especially relevant to this research: computer vision[101] and natural language processing. These subfields become relevant precisely because they allow a more direct interaction between humans and machines, as used in the DWS. This possibility is due to machine learning methods that have allowed striking image and speech recognition evolutions in recent decades.

Still, as a consequence of the need for interaction with humans demanded by the Turing Test, as mentioned in “1.3.4 Artificial Intelligence” the ability to communicate and perceive objects, among others, has been placed since very early in AI (Russell & Norvig, 2010). Thus, NLP and computer vision, among other skills, become an important tool for understanding the world and, consequently, a powerful interaction mechanism between humans and machines.

Natural Language Processing

Natural language processing is a subfield of AI and linguistics, concerned with understanding natural language, seeking both mechanisms to interact with humans in natural language and processes of data analysis in natural language. NLP can use supervised as well as unsupervised learning methods. Its main challenges are text classification, information retrieval (search

[101] Computer vision is an independent field of computer science that builds computer systems to work with imagery and pattern mappings and is commonly associated with AI as the two areas have many related developments. Significant innovations in computer vision have come precisely from their relationship with ML, leading many authors, including Russell and Norvig (2010), to have it as a subfield of AI. This research follows the understanding of Russell and Norvig (2010).

engines on the internet, for example), information extraction, machine translation, and speech recognition (Russell & Norvig, 2010).

For some of these tasks, NLP assumes the written text as being a set of characters (letters, digits, punctuation, and spaces), on which it is possible to apply a probability distribution over character sequences (Russell & Norvig, 2010). However, for other tasks—such as machine translation and speech recognition—it requires the notion that communication "is the intentional exchange of information brought about by the production and perception of signs drawn from a shared system of conventional signs" (Russell & Norvig, 2010, p. 888), which highlights the NLP potential as an interactive tool.

Accordingly, grammatical understanding becomes essential for developing a range of NLP algorithms. Therefore, computational logic incorporates some grammatical elements and rules, such as the *lexicon* (list of words allowed in the system), *syntactic analysis* (analysis of a sequence of words to understand its phrasal structure, according to the rules of a given grammar), among others. Moreover, it develops strategies to deal with lexical ambiguity, syntactic ambiguity, metonymy, and metaphor, for example, since language presents numerous nuances that are challenging to compute (Russell & Norvig, 2010).

Among the applications of NLP, speech recognition stands out as one of the most appropriate means to enable interaction between humans and computers. Its use is already quite frequent, and new applications are constantly emerging (in the DWS, for example), making it one of the leading AI applications. Briefly, *speech recognition* is the identification of a sequence of words uttered by a speaker when emitting a sound signal (Russell & Norvig, 2010, pp. 912–913).

A good part of the difficulties speech recognition faces comes from the ambiguity of the sounds emitted during the speech act. The main phenomena that leading to ambiguity in recognition of sound speech involve the issue of segmentation, coarticulation, and homophone sounds. *Segmentation* is the ability to recognize words in isolation, which becomes a challenge in the act of speaking because, unlike writing, spoken speech usually does not make the pause between words evident. *Coarticulation* of sounds happens when the sound signal of two words, or two phonemes, merge and appear to be one (a situation that may be more frequent in one language than another). Finally, there is also the issue regarding *homophones*, words that have the same sound but different meanings and grammatical functions, such as “to,” “too,” and “two” (Russell & Norvig, 2010, p. 913).

According to Russell and Norvig (2010), speech recognition can be computationally understood as a problem of explication of the most likely sequence. The problem lies in calculating the most likely sequence of variables for a particular state, given a sequence of observations. In speech recognition the state variables are the words, while the sounds are the sequence of observations; in other words, “an observation is a vector of features extracted from the audio signal” (p. 913). The most likely sequence strategy can be calculated by using the Bayes’ rule (p. 913).

Bayes’ rule is a simple equation, which is the basis of all modern AI systems grounded on probabilistic inference. Roughly speaking, the theorem seeks to calculate the *a posteriori* probability distribution for a set of query variables in the observation of a given event (Russell & Norvig, 2010, p. 522). In the case of speech recognition, for example, when the speaker says “ceiling fan,” and the system starts the processing of the first sounds, it identifies that the word starts with a soft “c,” which may lead to ambiguity between “ceiling” and “sealing.” However, the algorithm (supported by Bayes’ rule) checks the probability posteriori before each following emission, and, through this strategy, it realizes that the word “ceiling” is 500 times more likely to be linked to the word “fan” than “sealing” (p. 913). The development of this approach went back to the beginnings of AI and was called the *noisy channel model* by Shannon in 1948. For Russell and Norvig (2010):

> He [Shannon] described a situation in which an original message (the words in our example) is transmitted over a noisy channel (such as a telephone line) such that a corrupted message (the sounds in our example) are received at the other end. Shannon showed that no matter how noisy the channel, it is possible to recover the original message with arbitrarily small error, if we encode the original message in a redundant enough way. The noisy channel approach has been applied

> to speech recognition, machine translation, spelling correction, and other tasks. (p. 913)

Structuring of a speech recognition system still involves the definition of the acoustic and language model and the application of the Viterbi algorithm and, in most models, the adoption of the hidden Markov model (HMM). The Viterbi algorithm, the HMM, and the Bayes' rule are statistical models of probabilistic temporal reasoning (Russell & Norvig, 2010, p. 913). In addition to these statistical components, speech recognition systems usually develop an interface design that quests to induce users to give limited answers within a set of expected options, favoring a more reduced and controlled probability distribution (p. 917), as done in the DWS.

Broadly, these are the main mechanisms and strategies adopted in speech recognition systems. Russell and Norvig (2010) point to machine translation and speech recognition as the most evident applications in NLP and claim that both are based mainly on statistical principles (p. 919). The same influence of statistical approach is observed in various fields on the rise within computer vision, especially regarding applications aimed at image recognition.

Computer Vision

Computer Vision is an area of computer science, also framed as a subfield of AI (see footnote 101), which deals with the construction of artificial systems to obtain information from images. Three significant approaches stand out in this area: feature *extraction* through simple calculations, applied directly to sensor captures; *recognition*, where the algorithm seeks to distinguish among the objects identified, based on other information, usually visual, being able, according to the purpose of the application, to classify and label the information; and *reconstruction*, when the agent aims to build a geometric model of the world based on an image or a set of images (Russell & Norvig, 2010). This section will focus on image recognition, as it is an approach that enables more direct interaction with the user, as explored in the DWS. However, before that, it is relevant to understand, in general, how machine vision is processed.

Russell and Norvig (2010) detail how image capture mechanisms operate using sensors and, in parallel, as regards human vision:

> Image sensors gather light scattered from objects in a scene and create a two-dimensional image. In the eye, the image is formed on the retina, which consists of two types of cells: about 100 million rods, which are sensitive to light at a wide range of wavelengths, and 5 million cones. Cones, which are essential for color vision, are of three main types, each of which is sensitive to a different set of wavelengths. In cameras, the image is formed on an image plane, which can be a piece of film coated with silver halides or a rectangular grid of a few million photosensitive pixels, each a complementary metal-oxide semiconductor (CMOS) or charge-coupled device (CCD). Each photon arriving at the sensor produces an effect, whose strength depends on the wavelength of the photon. The output of the sensor is the sum of all effects due to photons observed in some time window, meaning that image sensors report a weighted average of the intensity of light arriving at the sensor. (pp. 929–930)

According to Russell and Norvig (2010), the image capture system distorts the appearance of the observed objects when creating them (as human vision does). In addition, other aspects influence the image synthesis process, such as the general light intensity, the ability to reflect light (diffuse or specular), and shading, among others (pp. 931–933). The color issue is also relevant: in this case, the trichromacy principle[102] facilitates the image processing by computer vision algorithms since each surface can be modeled with only three different albedos for R/G/B[103] (p. 935). A set of small dots forms the resulting digital image; each dot corresponds to a *pixel*, to which specific visual properties can be attributed, such as brightness, color, and texture (p. 941).

The three main image processing procedures are edge detection, texture analysis, and optical flow calculation. The *edge detection* is done by the sudden change of brightness in the different faces of the captured objects. *Texture*, in computer vision, corresponds to a pattern that is spatially repeated on a given surface and can be visually perceived. Lastly, the *optical flow*, observable in animated images, evidences the direction and

[102] Russell and Norvig (2010) explain that, “the *principle of trichromacy* states that for any spectral energy density, no matter how complicated, it is possible to construct another spectral energy density consisting of a mixture of just three colors—usually red, green, and blue—such that a human can’t tell the difference between the two. That means that our TVs and computer displays can get by with just the three red/green/blue (or R/G/B) color elements.” (p. 935)

[103] As also mentioned in the last footnote 102, R/G/B corresponds to Red/Green/Blue and they are identified by the acronym RGB.

displacement speed of attributes within a set of images (Russell & Norvig, 2010, pp. 936–941).

Segmentation is a processing strategy that breaks the image into smaller portions, defined by the affinity of characteristics such as brightness, color, and texture, associated with pixels. Generally, in an image, each object (or part of the object) has a significant similarity involving some of these characteristics (brightness, color, or texture), and which, concurrently, are sufficiently contrasting with those of the other objects in the image, allowing the identification of related areas and subsequent segmentation (Russell & Norvig, 2010). To Russell and Norvig (2010), "there are two approaches to segmentation, one focusing on detecting the boundaries of these regions, and the other on detecting the regions themselves" (p. 941).

After the initial processing of an image, it is possible to proceed with recognition by the appearance of objects. *Appearance*, in computer vision, is understood as a "shorthand for what an object tends to look like" (Russell & Norvig, 2010, p. 942). Specific categories of objects look very similar, like baseballs, for example. Objects of the same category tend to look like the same object in most instances, making recognition easier. In these situations, it is possible to calculate a set of idiosyncrasies describing each image class that bears a probability of containing the object. Subsequently, each image class must be tested with an instructed classifier (p. 942).

Some situations can, incidentally, modify the appearance of objects, making recognition difficult, as foreshortening, aspect, occlusion, and deformation. *Foreshortening* is understood as being the distortion caused by tilting an object. *Aspect* is the variation in how an object appears from its different perspectives (a chair can look very different when comparing its top view to its front view). *Occlusion* happens when parts relevant to the understanding of objects are hidden, either by their positioning or by other objects. Finally, *deformation* results from the capability, inherent to some objects, of modifying their appearance, such as, for example, the variation of shapes of a person with open or closed arms (Russell & Norvig, 2010, p. 944).

Recognizing objects in an image is a complex task. Supervised machine learning methods with extensive training examples have made this task more efficient. The development of Convolutional Neural Networks (CNN) by French Computer Scientist Yann LeCun (n.d.) in 1995 represented a considerable advance in the field. *Convolutional Neural Networks* are neural networks that have multiple interconnected layers, trained with a back-propagation algorithm, like almost all other neural networks. A significant differential of CNNs is that they were designed to recognize visual patterns directly from the image pixels, minimizing the need for processing as much as possible (LeCun, n.d.).

Having more specific neural networks and machines with growing processing capacity, image recognition has expanded considerably in a context where the use of digital images is increasingly frequent. This work—especially in the development of the DWS—is particularly interested in using the image recognition classification capacity as an interaction strategy with the user to work together with the speech system based on NLP.

4.4 Developing the DWS

4.4.1 DWS Apparatus

The DWS is composed of an apparatus that supports the digital window concept proposed in this research. Nonetheless, the development of the apparatus presented here is limited to being a prototypical version to support this system. The main goal of the research is not to develop a product but to demonstrate that the relationship of digital information with architectural spatiality can benefit the inhabitant. Therefore, the high-fidelity prototype developed is concerned with allowing the establishment of this relationship and the subsequent testing and validation of the research hypothesis (Chapter 5). It is also worth mentioning that other technological approaches can potentially be developed in pursuit of these objectives. However, this work deals with developing the alternative understood as the most appropriate and feasible within the context of its realization.

To meet the ambitions of the DWS, it is necessary to bring together three dimensions in the same apparatus. Hence, the DWS is composed of (1) electronic devices already on the market, (2) dynamic components created especially for this purpose, and (3) the application DWA (software developed supporting to both existing devices and devices designed exclusively for DWS). For the system to function fully, these three dimensions must work together.

The dimension regarding devices available on the market used in the DWS apparatus comprises a basic smartphone, projector, and IP-video camera. The smartphone acts as the central computer of the system. The projector can provide a screen adaptable to different surfaces and distances through light projection, allowing to visualize the digital window.[104] Finally, the IP-type video camera provides real-time images necessary for specific functions within the "see through" option (the technical sheets provided by the manufacturers of these pieces of equipment are available in

[104] The projector ("Annex C") used has automatic keystone correction technology, which can automatically adapt and correct distortions in the projected image resulting from changes in positioning. However, when the projection approaches the corners, the image is distorted.

"Annex B," "Annex C," and "Annex D"). In addition, these three devices can remotely connect when linked to the same wireless internet network, which is necessary for operating the DWS.

The dimensions of dynamic components and the application are closely related. However, it is up to the DWA to relate the dimension of the dynamic components with the devices of the first dimension. Dynamic components are the subsystems developed to provide the DWS with certain spatial freedom through swivel support and its respective dynamic positioning control mechanism (called issuer control). Finally, the DWA is responsible for the core functionality, interfaces, and means of interacting with the DWS (including the NLP and computer vision-based methods discussed earlier).

Based on the aggregate of these three dimensions, formed by relatively simple parts, an apparatus of considerable complexity is generated. Such an apparatus allows the DWS to match those functionalities discussed in "4.2.2 Composing the DWS," to have the multiplicity of interactive media described in "4.2.3 Interface and Interaction," and to supply the spatial approach required by the digital window concept. Next, the processes for creating the parts necessary for realizing the DWS are described and detailed: its dynamic components and the Digital Window App.

4.4.2 Dynamic Components

In this section, the objective is to detail the development of the physical parts ("Appendix 4A" and "Appendix 4B"), the connections of the electronic components employed ("Appendix 4C" and "Appendix 4D"), and the algorithms developed ("Appendix 4E" and "Appendix 4F") for the devices designed to provide the DWS with a responsive mobility to the inhabitant. First, however, it is noteworthy that the three devices added to the DWS apparatus—smartphone, projector, and video camera—have their hardware and software developed by the industry and are available in the market, regardless of any achievements arising from this research.

Allowing the visuality of digital information to traverse the physical limits that shape domestic spatiality is a notable point within the digital window concept. In this approach, mobility in displaying digital content is one of the means of integrating it into the space. Accordingly, the system allows the inhabitant to have control of this mobility and the freedom to choose the position according to the routine, needs, and particularities of domestic space. Therefore, the dynamic question is a point of great pertinence within the DWS context.

The general inspiration for these dynamic engines comes from films featured in "2.4.2 Cinematographic Narratives" and mentioned in "4.2.2 Composing the DWS." The idea of using the projection of digital information to link the screen to the wall is comparable to what happens in *Minority Report* (Spielberg, 2002) in its "wall screen" (see *Figure 2.11*). In this film, it is still possible to envision means of controlling digital information using the body (and hands) more directly, which is also relevant for the DWS. Regarding the possibility of moving digital information through the domestic space, the reference is the apparatus shown in the film *Blade Runner 2049* (Villeneuve, 2017), where a kind of mechanical arm installed on the ceiling supports the displacement of a holographic projector through certain parts of the protagonist's apartment during the film (see *Figure 2.12*).

Swivel Support

The DWS' swivel support was developed to be installed close to the ceiling and is composed of three parts (see *Figure 4.2* and "Appendix 4A"):

1) The upper part, fixed to the ceiling, having a diameter of 268 millimeters, where the electronic components that coordinate and execute the movement are installed, including a communication sensor with the issuer control.

2) The central shaft, with a diameter of 25 millimeters, is a metallic tubular part attached to a square flanged ball bearing (model UCF 205) and permits the rotation between the fixed upper part and the rotating lower part (the interior of the metallic central axis nests the power cable of the projection equipment).

3) The lower part, with a diameter of 410 millimeters, delimits the space where the projector is sheltered.

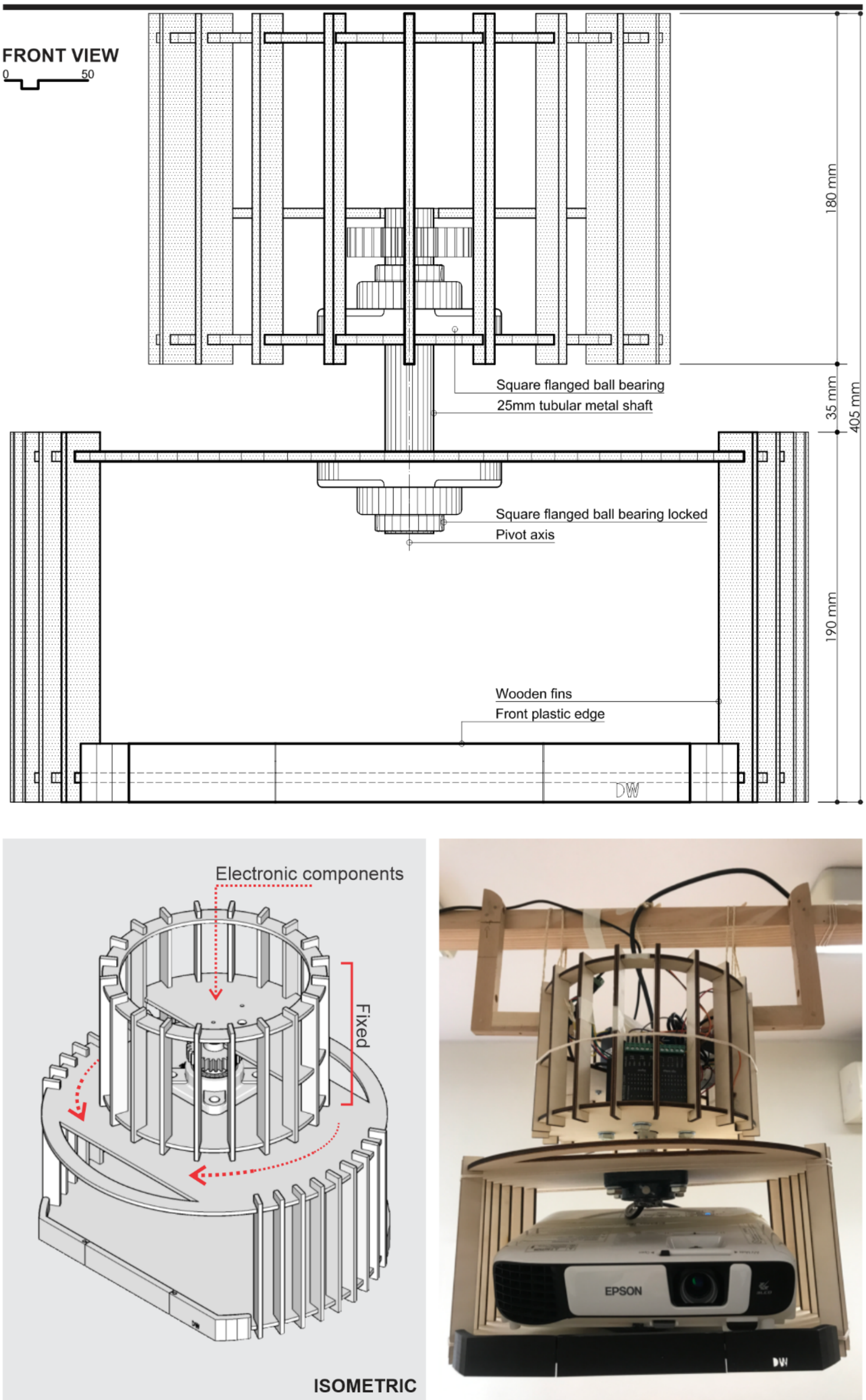

Figure 4.2 *Swivel support. Top panel: front view on the top; bottom left panel: isometric and schematic information; and, bottom right panel: final result*

As the primary function of the swivel support is to perform concentric circular movements, the cylindrical shape proved to be the most appropriate.

Therefore, the upper part forms a cylinder 180 millimeters high, consisting of an upper ring, a circular base, and a semi-circular intermediate platform for fixing and supporting the engine. These three pieces are interconnected and structured by 20 fins arranged in an equidistant and concentric manner (see *Figure 4.2* – Top panel).

The lower part consists of three elements, the first one being a circular plate with cutouts that allow to insert the hands for transporting the set (see *Figure 4.3* – Top left panel); Next, a lower circular base with a front cutout makes the surface where the projector is placed. Finally, 18 fins are arranged laterally, divided into two symmetrical groups, with a height of 190 millimeters. Added to this set is the aforementioned metallic axis that connects them through their respective central points. In total, the swivel stand is 405 millimeters high.

The swivel support project sought to create a light, suspended structure, assembled by fittings and with the necessary strength to support the sum of its own weight and the weight of components, projector, and the gravitational force that acts on the set once the support is hoisted from the floor.[105] For most pieces, laser-cut plywood (five mm plywood) was chosen (see *Figure 4.3* – bottom panel). In addition, some small supporting parts were designed to be digitally manufactured using plastic filaments. Both parts were modeled in CAD software and generated files in DXF (Drawing Exchange Format) and STL (Standard Triangle Language) extensions compatible with the machines of the *Laboratório de Prototipagem Rápida* (LPR) at FA.Ulisboa, where they were produced.

The wooden parts were laser cut with a CNC machine (Computer Numerical Control). Due to the precision of the cut, the wooden parts were proposed to be assembled by “male-female” type fitting (see *Figure 4.3* – top right panel). Nonetheless, this strategy made it necessary to use punctual lashings to ensure that the assembly did not arbitrarily disassemble. Thereby, the purpose of using the fitting and tying of the parts was to allow

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[105] The set weighs approximately 6 kg (swivel support structure: 0.84 kg; motor: 0.73 kg; other electronic components: 0.47 kg; two iron bearings: 1.44 kg; and projector 2.5 kg. The sum of these parts totals 5.98 kg).

easily disassemble and reassemble it, should any adjustments to the electronic components come to be necessary during the tests (which happened several times).

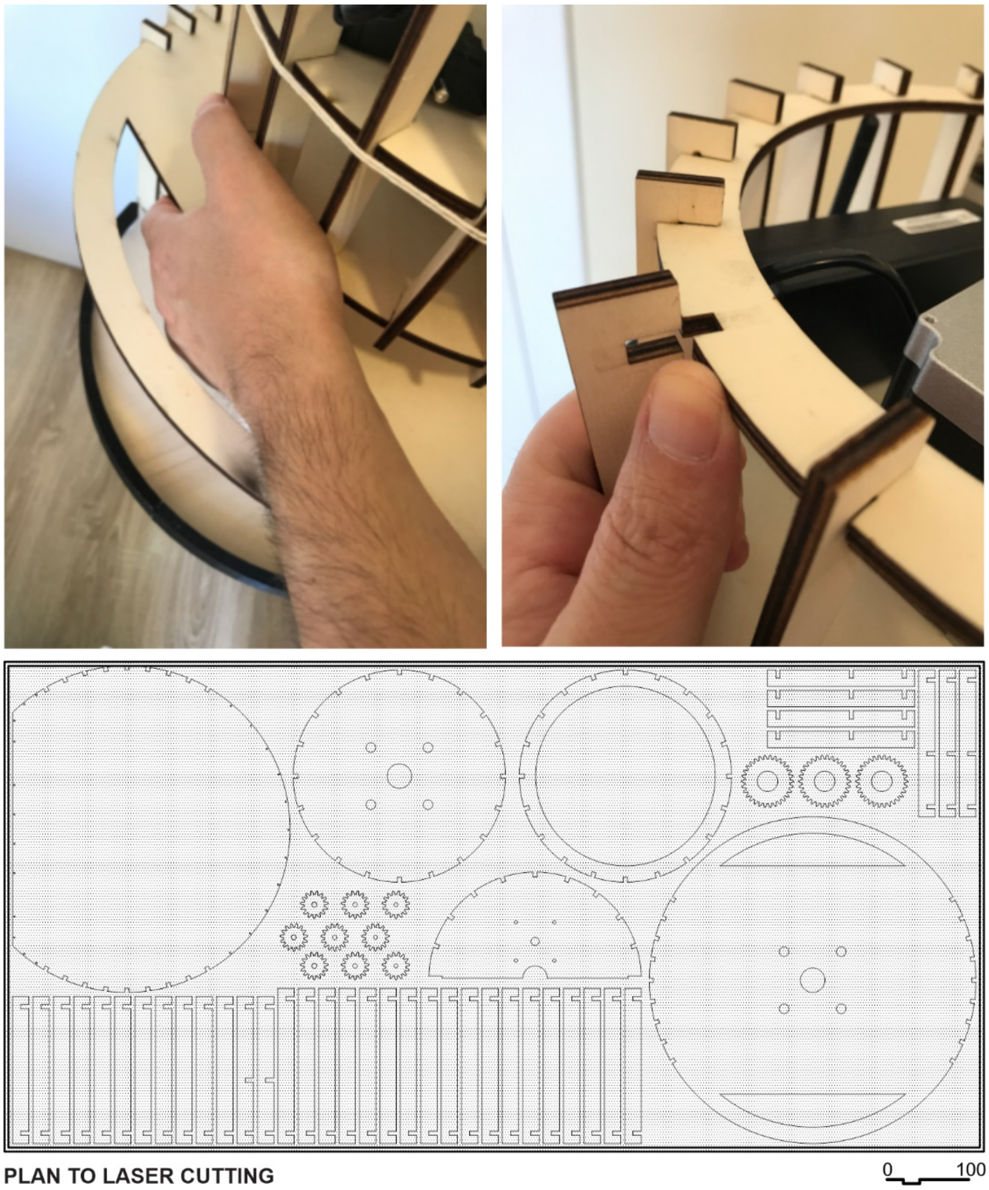

***Figure 4.3** Swivel support details. Top left panel: handle for manual transport; top right panel: male-female fitting; and, bottom panel: plan to laser cutting*

The supporting parts applied to the lower piece were digitally fabricated using plastic filaments in an FDM (Fused Deposition Modeling) printer, as well as the body of the issuer control shown in the next topic. The parts applied to the swivel support created an edge to prevent falls in case of displacement of the projector (which did not happen, neither in the preliminary tests nor during the realization of the final test).

As part of its mechanical components, the system has two gears that transfer the rotation movement of the motor to the metallic shaft. A larger gear is inscribed in a 64 mm diameter circle, and a smaller one is inscribed in a 34 mm diameter circle. Initially, these pieces were manufactured using both in plastic and wood. However, during the testing phase, wooden gears proved to be a more resistant alternative and, thus, are the ones equipping the final version of the prototype. These wooden gears were also laser cut out of a five millimeters sheet, and three equal pieces were superimposed on each other to create the gears with the adequate height (15 mm).

A set of electronic components (sheltered in the fixed upper part of the swivel support) were necessary to let the device perform the desired movements and obey the issuer control. Of this set, the processing board (of the "single-board computer" type) stands out, the stepper motor, the driver for stepper motors, the radiofrequency receiver module, the power supply, and the voltage converter module. A mini breadboard and jumpers were used to electronically interconnect the components.

The processing board—Arduino UNO R3 type—receives via USB connection the code developed to allow the swivel support to work (described later). This board works as the computation center that processes the system inputs and outputs using the instructions of the previously loaded algorithm. This process starts when the power supply (12V and 5A) is connected to the power grid, and the LM2596 type converter module regulates its voltage. Once the module converts the voltage, it feeds the motor driver (which feeds the stepper motor) and the processing board that, in turn, feeds the radio frequency receiver module.

The radio frequency receiver module, NRF24L01 type, is a wireless device equipped with a long-range receiving antenna, which receives the position signal emitted by the issuer control (through a location sensor on the control). Once the information from this receiver is supplied to the processing board, it communicates with the stepper motor controller (driver TB6600 type), which coordinates the operation of the motor. It is worth remembering that this driver is connected to the voltage converter module, so it orchestrates the power supply that drives the motor to operate according to the coordinates received from the processing board (see *Figure 4.4* and “Appendix 4C”).

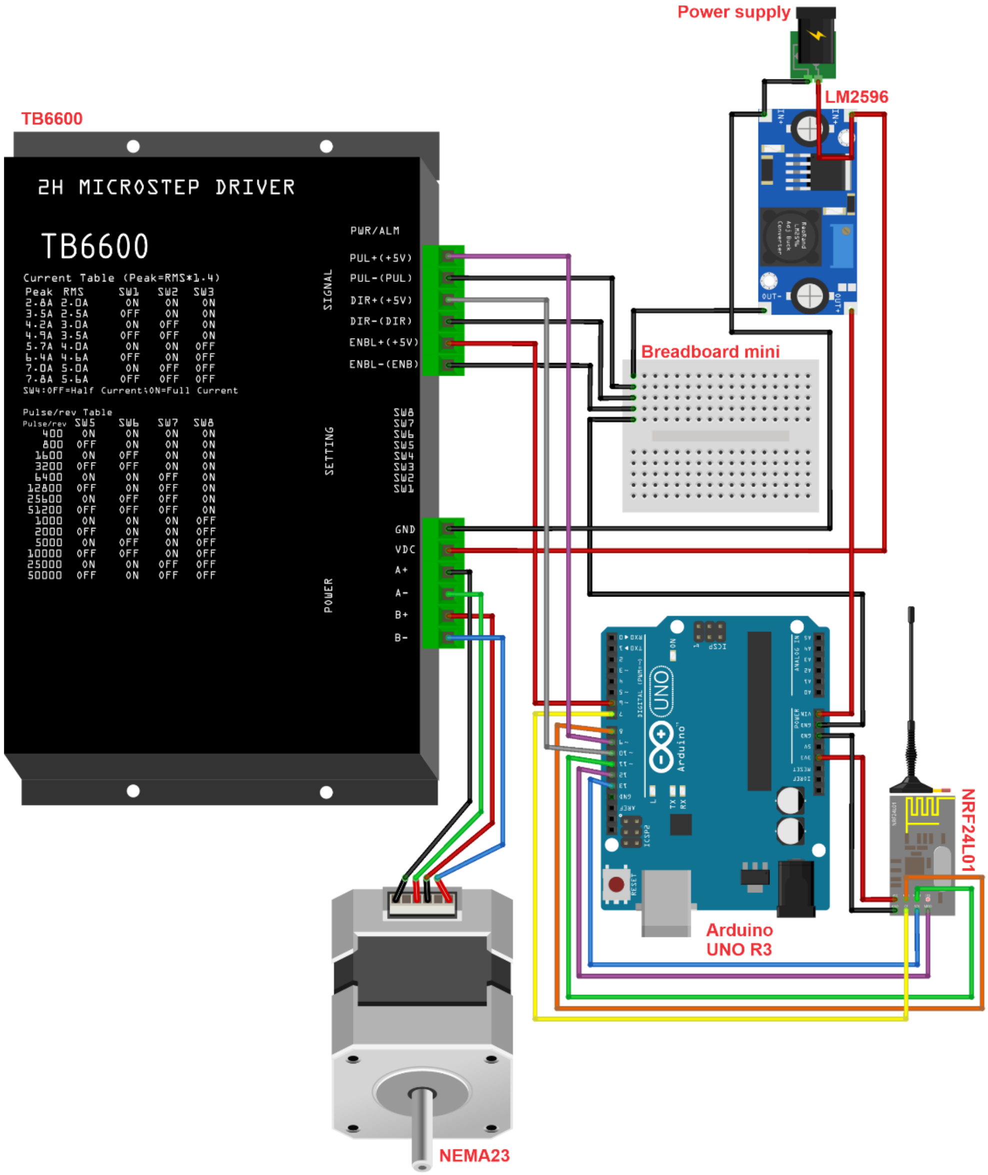

Figure 4.4 *Swivel support component connections diagram*

The stepper motor used, NEMA 23 type, is capable of operating a complete revolution (360º) in 200 steps, equivalent to an angle of 1.8º per step, with a torque of 14 kg.cm. This motor turns the gears described above, which transfer the rotation to the tubular metallic shaft. This axis is fixed in the center of the first panel in the lower part of the swivel support. Thus, every axis movement immediately turns this lower part, where the projector is inserted.

Briefly, this arrangement of the electronic components allows the mechanical movements of rotation. To create the algorithm with the instructions that coordinate this process, the Arduino platform (Arduino.Ink) was used, the same one that permits the loading of this code via USB to the processing board. As a result, the algorithm developed is relatively simple and short (the code can be seen in its entirety in “Appendix 4E”).

The algorithm uses some libraries from the Arduino repository, emphasizing libraries developed to deal with the NRF24L01 type radio frequency receiver module. Next, the declaration of the pins (referring to the available inputs on the processing board) are established, and then the necessary variables. Subsequently, the values of variables referring to the current (“currentPOS”) and previous (“previousPOS”) positions are provided by the radio frequency receiver module. However, before that, they are generated by the position sensor existing in the issuer control and transmitted by the radio-frequency transmitter module existing in it. This exchange of information between these devices is essential within the DWS context, as this is the resource that allows the DWS to have the dynamic interactivity mentioned in “4.2.3 Interface and Interaction.”

The code sequence includes other instructions and relationships among these variables, the outputs, and other determinations. The instructions also determine the initial turns, coordinating their direction and execution time. This introductory system arrangement is part of the spatial interface mentioned in “4.2.3 Interface and Interaction.” In detail, the movement lasts 30 seconds and starts with a 360º turn to the left (15 seconds duration) and a right turn to return to the starting position (15 seconds duration). At the same time, the digital window projection displays an animation that introduces the application, in coordination with these movements, which will be detailed in “4.4.3 Digital Window App.”

Issuer Control

The device called “issuer control” is, in short, a mechanism that shelters the position sensor (MPU6050) and a radio frequency emitter module (NRF24L01). Therefore, the issuer control is responsible for transmitting the inhabitant’s position referencing in the context of the DWS. As previously mentioned, the purpose of this prototype is not to develop a product for the market. Consequently, aesthetic and practical aspects regarding prolonged use by a typical consumer were not considered. Instead, the central concern was to allow the inhabitant's body position to be computed by the system so that it can respond to such input.

The issuer control was initially thought to be parked over the user's head in a specific position.[106] In this way, with the simple resource of a head bow attached to the issuer control apparatus, it is possible to keep the system informed about the direction of the inhabitant's eyes, which is relevant in the DWS logic. However, depending on the user's wishes or other circumstances, the issuer control can be disconnected from the head bow and rest on a flat surface (like a support table, for example). In this situation, the position is determined by the direction chosen manually by the user.

The body of the issuer control is a one-piece, horizontally predominant plastic piece, 30 millimeters thick (see *Figure 4.5* and "Appendix 4B"). The piece displays a triangular shape with three rounded corners when viewed from above. This isosceles triangle has a base that measures 100 millimeters, and its height measures 160 millimeters. In addition to trying to shelter the various electronic components needed in the smallest possible space, such format also sought to take advantage of the shape to indicate with visual clarity the direction of the control since it always "points" to where the digital window is projected.

The control is powered by a 9V rechargeable battery, with an opening designed for recharging (see *Figure 4.5* – bottom right panel). By turning on the control switch, the energy passes through the voltage converter module (LM2596 type, the same used in the swivel support), going directly to the mini breadboard and the reduced processing board (Arduino nano V3.0). Through the mini breadboard, both the MPU6050[107] sensor and the

[106] It should be repeated that this is an experimental approach, and it is not based on the belief that users of the system would wear a device of this type on their heads for hours. If it is considered a hypothetical logic, where the approach proposed here evolves into a consumer product with industrial support, a large team of the most varied professionals would probably work to make this type of device viable for routine and prolonged use.

[107] The MPU6050 component is a sensor that can bring together three axes for the accelerometer, three for the gyroscope, and a temperature sensor in just one chip (information from the manufacturer). In the case of DWS, only the three axes of the gyroscope are used.

NRF24L01 radio frequency emitter module are powered. They are also connected to the processor board pins to allow the code loaded on the board to receive and process the information that will be sent to the swivel support, determining its movement (see *Figure 4.6* and “Appendix 4D”).

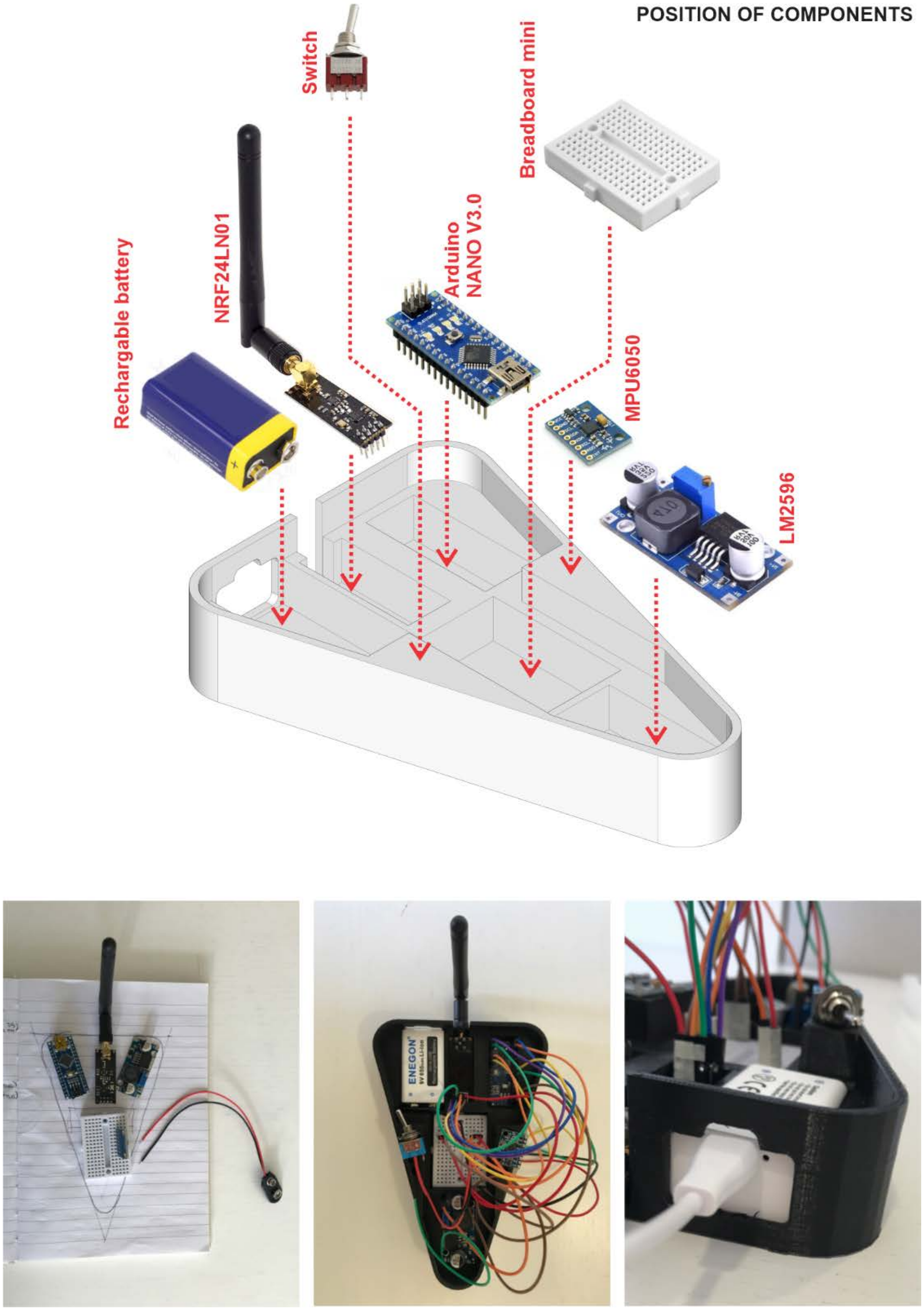

Figure 4.5 *Issuer control. Top panel: position of components in the control body; bottom left panel: sketch and planning; bottom center panel: final result; bottom right panel: opening for battery charging*

Thus, in summary, it is possible to say that the operation of the issuer control happens as follows: The LM2596 voltage module regulates the energy supply received from the rechargeable battery and sends it to the components; the gyro sensor present in the MPU6050 constantly reports its own position. Then, the processing board receives this information and processes it according to the code developed especially for the control; sequentially, the processing board sends the necessary data to the swivel support through the radio frequency transmitter module NRF24L01 (see *Figure 4.6*).

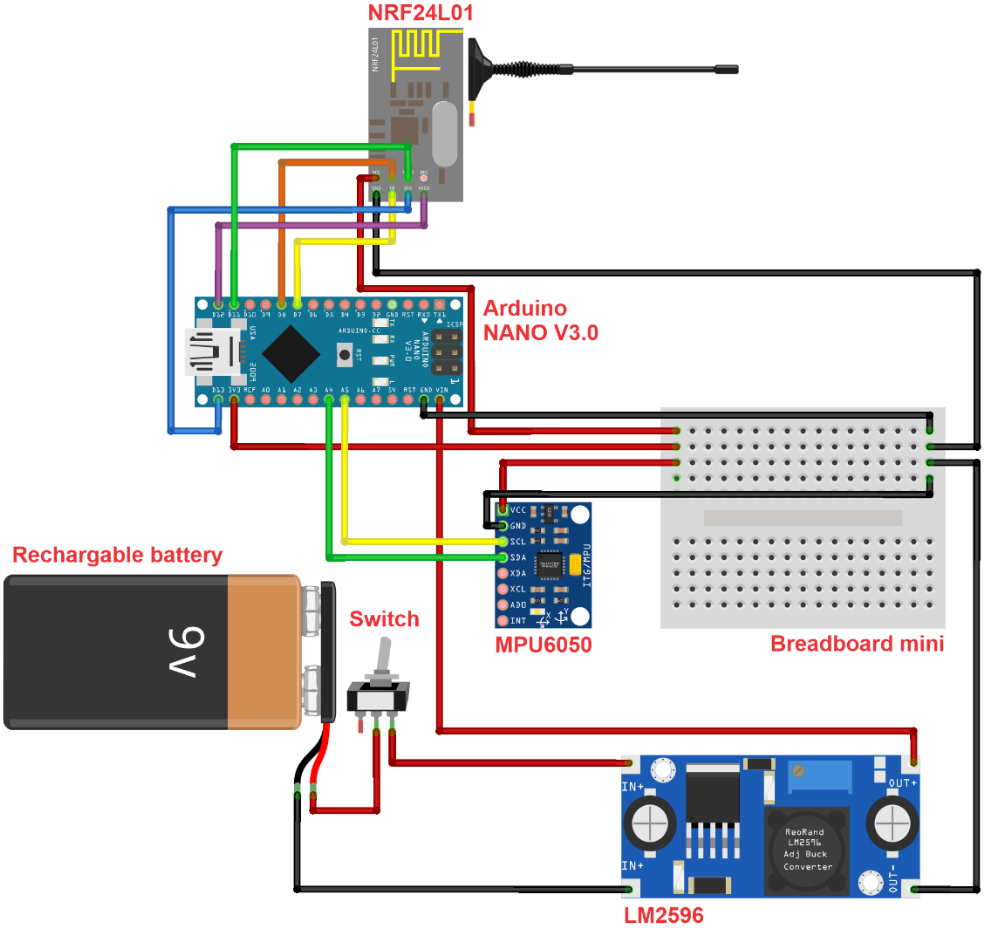

Figure 4.6 *Issuer control component connections diagram*

The issuer control algorithm has the same general structure as the swivel support algorithm and was also developed on the Arduino.Ink platform (and can be seen in full in "Appendix 4F"). Therefore, in the beginning, the libraries of the most relevant electronic components are included, highlighting the operation libraries of the MPU6050 sensor and the NRF24L01 radio frequency emitter. Next, the processing board pins are declared, and the code variables are named. These variables are related to position data (input); consequently, the results of operations involving this data are sent to the swivel support (output).

Following instructions from the algorithm, the position reading is updated every second, and if it remains unaltered, nothing happens. However, if any significant difference is noticed, this results in changing the position of the swivel support and, consequently, in the projection of the digital window. Accordingly, the system can be responsive to the inhabitant's body (or user's intentionality), executing an eventual displacement of digital information through the domestic space.

The process of making the swivel support and the issuer control went through some stages of evaluation and consequent modifications according to the evolution in the prototype development. After a few versions of the project, the execution of the swivel support structure was successfully carried out on its first attempt. On the other hand, the issuer control body had to be readjusted and re-fabricated three times due to sizing problems and the need to add components not initially planned. Once the physical structure and components were ready, the improvement of the codes required constant tests, mainly to verify their operation, sensitivity adjustments to the movement of the issuer control, and speed of rotation, among others. The final code for the issuer control is its 18th version, and for the swivel support is its 24th version.

At the end of this process, a substantial part of the DWS prototype was ready. Along with these achievements, the Digital Window App was under development to be able to add the functions, interfaces, and interaction methods to the system, as described at the beginning of this chapter. Next, the process of creating this application is described, focusing on programming the essential resources to complete the DWS apparatus.

4.4.3 Digital Window App

The choice of a smartphone-type mobile device as the "central computer" of the DWS apparatus is justified mainly due to its mobility and great assimilation by the population. In addition, a relatively simple mobile device available on the market already has sufficient processing capacity for what is proposed in this research (see datasheet in "Annex B"). Moreover, in Chapter 3, the data from the DTL survey showed that this type of device is already an element present in many homes of older adults that made up the survey sample. The survey showed that almost 40% of the total sample already owned a smartphone, and almost 60 % of the sample that responded to the online survey already had a smartphone, as discussed in “3.3 Domesticity and Technology in Lisbon.” Due to this choice, developing an application (app) as part of the software that integrates the hardware of the DWS apparatus becomes an expected consequence.

The Digital Window App aims to digitally structure the functions, interface, and means of interaction discussed in “4.2 DWS Fundamentals.” It should be noted that the DWA was not developed to be used in isolation as a standalone application; therefore, its use is only justified when integrated with the DWS apparatus, being a fundamental part to it. The building of an algorithm that supports these ambitions on a mobile device was elaborated using a block-based programming language, made available by the educational development platform maintained by MIT, the *MIT App Inventor*[108] (*MIT App Inventor 2*, n.d.).

The block-based programming language (also known as *blockly*) is considered a visual programming language (VPL). It uses graphic elements that initially employed a *JavaScript* library, allowing the easy insertion of commands, variables, procedures, strings, and textual components, among others (*Blockly*, n.d.). Besides, its graphical interface, based on drag and drop, provide a more friendly interaction, ideal for apprentices or professionals not initiated in computer science, as is the case of most architects, for example.

Briefly, the history of the development of programming language based on blocks is recent and linked to MIT, where it was developed by the MIT *Media Lab* and launched in 2003. Programming is born in the context of *Scratch*, an open-source software that allows to program and control graphic actions through programming by blocks and focuses on children’s education as an introductory path to programming. One of its inspirations

[108] The current version of *MIT App Inventor* can also be called *MIT App Inventor 2*, while its original version is currently known as *MIT App Inventor Classic* (*MIT App Inventor*, 2020).

comes from *Lego* toy blocks, where small blocks are ordered to compose a more complex object (Resnick et al., 2009, p. 63).

With the proliferation of smartphones, the block programming approach—in addition to remaining as a start-up tool for programming—has also been devoted to democratizing application programming for mobile devices. In this context, the *MIT App Inventor* project arose, initially developed by a *Google* team in 2009; and soon after transferred to MIT together with resources for the creation of the MIT *Center for Mobile Learning*, currently integrated with the MIT *Computer Science and Artificial Intelligence Laboratory* (MIT CSAIL) and the MIT *Media Lab* (Clark, 2013).

Two years later, in 2012, the team led by Professor Hal Abelson launched the *MIT App Inventor* platform, which is free to use and open source (*MIT App Inventor*, 2020). Currently, many other platforms emerged inspired by the *MIT App Inventor*, which also allows the development of applications for mobile devices using block programming languages, such as *Thunkable* and *Kodular*, which are not used in this research.

The development of the *room_ID* application, subject of the article "*room_ID*: An Architectonic Image Classifier Tool Correlating Machine Learning and the Domestic Space" (Nogueira & Romão, 2022), mentioned in "g. Academic Developments," had already made it possible to relate block programming to AI (image recognition) through the *MIT App Inventor* platform. Based on this experience, *MIT App Inventor* proved to be a suitable path for developing the DWA. Even though some limitations are perceived (and will be mentioned throughout this section), *MIT App Inventor* enabled the creation of the DWA, a single application capable of bringing together two different AI tools (NLP and image recognition). Furthermore, *MIT App Inventor* also permitted establishing specific functions referring to the metaphor regarding *janelar* in the DWA, composing the graphical interface, and taking advantage of features present on the mobile device (such as making an emergency call, for example).

For creating the Digital Window App, it was necessary to use blocks that allowed declaring variables, establishing procedures, and adding control tools (such as those that bring together traditional routines in the programming universe, such as "if," "if-else," among others), text blocks, strings, creation and manipulation of lists, inter alia. As an example, *Figure 4.7* presents a small snippet of the DWA programming that illustrates the use of blocks in the declaration of a variable, determination of a procedure, and control block, with blocks of logic (in this case, "true" and "false").

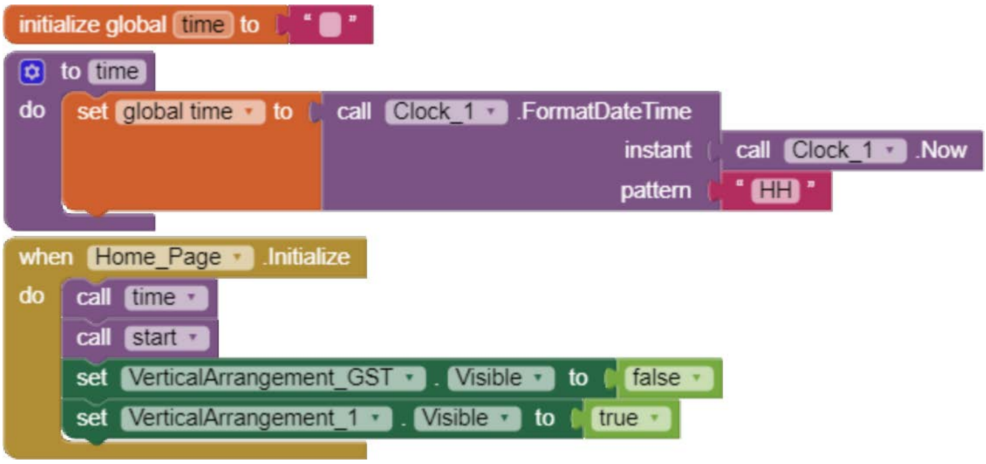

Figure 4.7 *Example of blocks used in the Digital Window App*

On *MIT App Inventor*, software creation is structured by inserting screens, so each application screen has its own block structure, independent of the others. In specific cases, it is possible to transport information or values from one screen to another, but it is not possible to make a function present on one screen act on another automatically, unless the same function is re-inserted on the other screen. In the case of the DWA, this programming ordering mode facilitated screen-based segregation of duties. Therefore, the functions of *janelar* were built on specific screens; for instance, "Window 2" was responsible for the functions related to social interaction, which were structured on the "DW_2" screen.

However, a disadvantage of this process is that functions common to the various screens, such as interaction and emergency call (SOS) methods, need to be repeated on practically all screens. This fact, together with the inherent visual aspect of the language (space-consuming), made programming extensive, as can be seen in the "Appendix 4G." Creating extension components, which work as adjacent algorithms with specific functionality, could eventually be a solution. Nevertheless, they were not explored in this research due to the difficulty in establishing an appropriate relationship between what should be kept for all screens and what is particular to only one.

Therefore, it was more practical to reproduce the blocks in the different screens and change them according to the specificity of each screen, since the DWA deals with a few screens (10 in total and nine where this question applies).

Introduction screen and main menu

The first DWA screen is called “Screen1” by default in *MIT App Inventor* and cannot be renamed. On this screen, the activation of the communication with the set formed by the dynamic components (“4.4.2 Dynamic Components”) was programmed. Additionally, a list was inserted with a set of images created specially to form the opening animation of the application. This first screen was configured to be displayed in landscape mode[109] per the animation developed. The timing of this presentation is controlled by a temporal sensor (the smartphone timer), following instructions defined through control blocks, which, after 30 seconds, automatically directs the user to the second screen (“Home_Page”).

The “Home_Page” screen is the main DWA menu, and in *Figure 4.8*, it is possible to see how this screen relates to the other windows. For this screen, an initial procedure was programmed to update the variable “time” so that the current time determines the greeting given to the user (among “good morning,” “good afternoon,” and “good evening”). This information is displayed textually and via audio output (using the “TextToSpeech_1” component). This detail, in addition to seeking the establishment of a more friendly and humanized interface, already shows that the user can, if wished, establish a dialogue with the computer, selecting the function they would like the system to operate through the NLP. In addition to the text box that displays the opening greeting, the start menu—arranged to be displayed vertically—also features an image of the application logo at the top. Next, there are four buttons for each of the windows closest to the center. Finally, one can find the three icons at the bottom of the screen.

[109] Regardless of how the smartphone is held or positioned, the projection of visual content follows the vertical or horizontal arrangement according to the instructions entered to the algorithm on all DWA screens.

The central icon at the bottom of the screen is highlighted with a red circle. This button activates the “SOS” procedure, which makes an emergency call whenever pressed, being present on all screens (except for the opening screen mentioned above). This procedure can be requested either by this button through touch or by gesture and voice commands. The other two icons adjacent to “SOS” refer to the AI-based interaction tools discussed in the previous section, “4.3 AI and the DWS,” and can be better understood with the help of *Figure 4.9*.

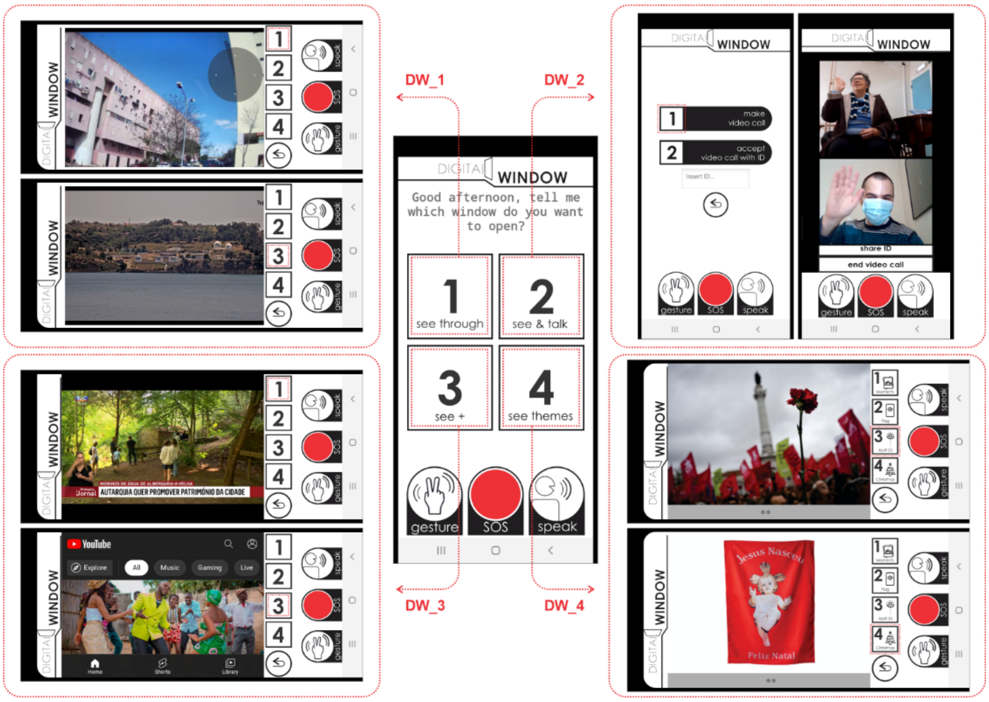

Figure 4.8 *“Home_Page” screen, access to the four windows and general graphical interface*

The “speak” icon uses NLP tools to recognize the user’s sound signals (words). The word is recognized and received by the system as the input that configures the “windows” variable of the “SPK” procedure. In sequence, if this variable coincides with the strings already listed in the procedure, they trigger specific actions, such as accessing a particular window, for instance. If the response does not match, the “SpeechRecognizer_1” extension opens the microphone again to pick up a new voice response. In *Figure 4.9*, it is possible to observe some examples of words configured to respond to voice commands.

While some activation words remain the same through the screens, such as those that activate the emergency call, others adapt to the specifics of their own screen. Thus, on the “Home_Page” screen, the word “one” allows opening “Window 1,” for example; and in “Window 1,” the word “one” opens the first option offered on the “DW_1” screen, which refers to being able to view the content displayed by the IP camera that makes up the DWS apparatus. Additionally, there are also specific words for each screen that are not repeated in the others.

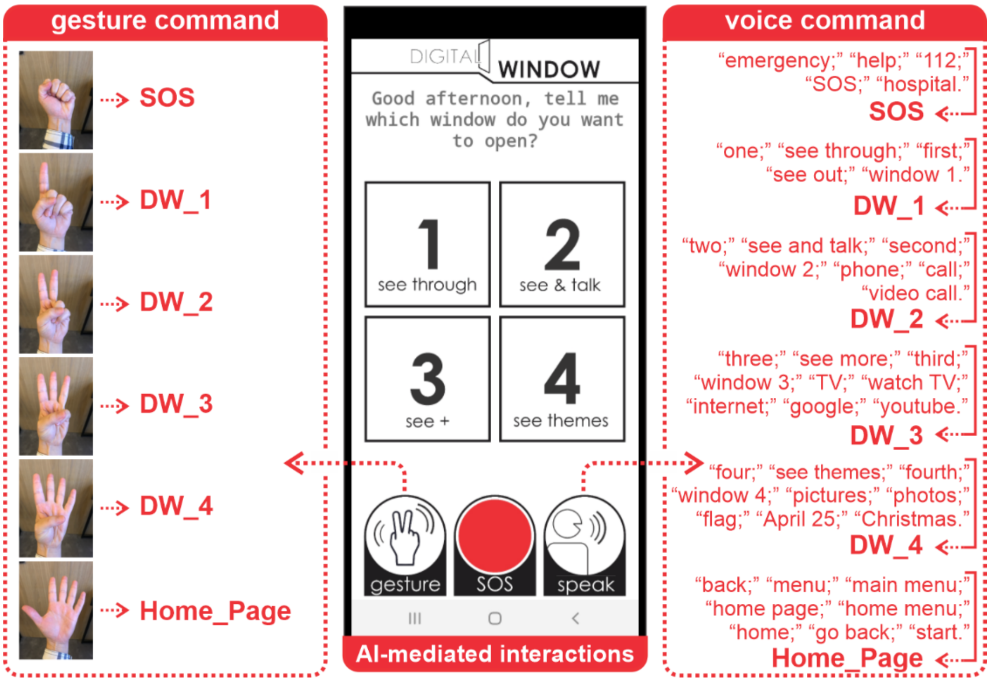

Figure 4.9 *AI-mediated interaction methods*

The “gesture” icon operates in a relatively similar way, though based on image recognition. Through the extension “PersonalImageClassifier_1,”[110] provided by *MIT App Inventor* and by PIC (*Personal Image Classifier*, n.d.), it was possible to create six labels based on six hand gestures. Each label was fed with a set of reference images, creating an input-output pair based on ML neural networks. This process generates a specific algorithm (.mdl) incorporated into the DWA and coordinated by the said extension. The *MIT App Inventor* AI-team developed and keeps this component available for uses like this. The statistical classifications obtained by this apparatus feed the procedures and the control tool responsible for gestural interaction

[110] According to information available on the *MIT App Inventor*, this extension is an altered form of “WebViewer,” developed by Danny Tang. The version of the extension used is identified as 20210315, built-in 03/15/2021.

(output). This way, it is viable to associate the label resulting from the image classification with commands to access specific functionalities.

This process is alike to the one developed in the *room_ID* application but with different recognition objects. However, the working mechanisms of the forecasts are the same. It is worth mentioning that as this method is based on statistical calculations, its success rate is variable. Due to limitations of the means and equipment used in developing this classification model, each label was fed with 250 images, a number considered low (for *room_ID*, 1000 images were used per label, for example). Nevertheless, samples with 250 images, in the context of this research and the other parts of the system, can be considered acceptable since, with this sample size, it was already possible to have an accuracy rate of 93.3%, verified during the test (two errors in 30 attempts). In future works or possible evolutions of this research, this would be a critical point to be addressed so that both quantity and diversity of images that make up the samples can be expanded.

"Window 1"

As for "Window 1," it is also called "see through" in the graphical interface and referred to as the "DW_1" screen in programming developed using the *MIT App Inventor* platform. As can be seen in *Figure 4.10*, its graphical interface uses the horizontal display of information (landscape mode), seeking to favor horizontal video content (a format commonly used by the types of camera and video viewers inserted in this window). The image with the DWA logo is in the leftmost portion, which also functions as a button that returns to the "Home_Page" screen. Most of the screen space is dedicated to video content, exhibited through a component that allows displaying web pages ("WebViewer"). On the right of the screen, a set of vertically aligned buttons, numbered from one to four, was inserted, and in the lower portion of this column of buttons, there is the circular icon that signals the return option (returns to the "Home_Page" screen). Finally, in the rightmost portion are the emergency button and AI-based means of interaction discussed earlier (duly adjusted to the specifics of the "DW_1" screen).

The programming of this window is relatively simple since the options of views offered to users are procedures based on the connection of an online content link in real-time and a component of the type “WebViewer.” Even in the first option, where it was necessary to physically install an IP-type camera (mentioned in “4.4.1 DWS Apparatus” and with datasheet in “Annex D”) and then host it on a website that provides this kind of service. The logic of incorporating the resulting link into the DWA’s schedule has remained the same.

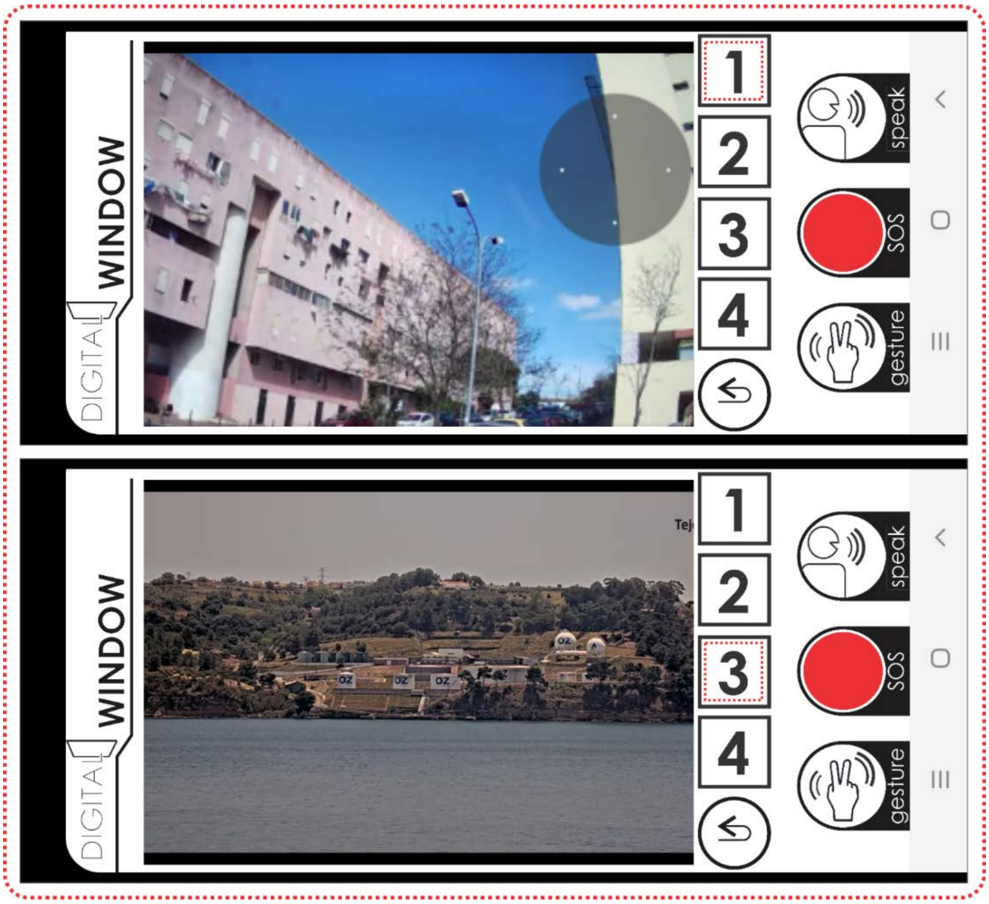

Figure 4.10 *Demonstrations of “Window 1”*

The “Window 1” proposal allows DWS a unique architectural possibility, where it becomes feasible to simulate transparency on an opaque surface.[111] Therefore, the DWS apparatus provides an experience that, in some way, corroborates with questions regarding the materiality and hybridization of space, proposed, respectively, by Picon (2003) and Teyssot (1994, 2005), as mentioned in Chapter 2. Furthermore, such a simulation gains some verisimilitude when the image offered is of a possible view if an opening existed

111 Even using another type of apparatus, this type of visualization, so strong in the metaphor of the digital window, had already been explored in the article “Toward a Digital Window” (Nogueira et al., 2020), mentioned in “g. Academic Developments,” and presented in the “Appendix C.”

in the hypothetic wall,[112] which is offered by option "1" of "DW_1" and can be seen at the top of *Figure 4.10*.

The second and third options display real-time images of Lisbon: While camera 2 switches the display to traditional points of the city (Castelo de São Jorge, Sé de Lisboa, Terreiro do Paço, among others); camera 3 displays different points of the Tagus river seen from the Lisbon bank, looking at the south bank (see the lower part of *Figure 4.10*). Finally, camera 4 displays urban images of Madeira Island. This last camera was chosen to show users the different options and real-time viewing range offered by the DWS apparatus, providing images from overseas.

"Window 2"

"Window 2" is identified as the "DW_2" screen in the algorithm and as "see & talk" in the graphical interface. This window allows realizing a video call that intends to provide some type of social interaction (see *Figure 4.11*). This function is inspired by the conversations that take place next to windows facing the public road, as verified and described in "3.4 *Janelar*." To develop this function was necessary to resort to video streaming through the "CustomWebView_1" extension[113] and the non-visible component "Sharing_1," native to *MIT App Inventor*. Briefly, the video call procedure starts when the "permission" variable changes, according to the user's response to the dialog box (pop-up) that appears when "DW_2" is opened. If the user's response is permissive ("YES"), the system can then access the smartphone's video camera, capturing and transmitting audio and video.

In the continuity of the procedure, the "CustomWebView_1" extension establishes a connection between the information provided by the camera and the "WebViwer" component. This extension also is responsible for

[112] While carrying out the test in Lóios (which will be discussed in the next chapter), this procedure allowed the DWS to provide the view that would be possible if there was an opening in the wall delimiting the room where the test was conducted. In this way, it was possible to see the emblematic social housing building "The Pink Panther" by Architects Gonçalo Byrne and António Reis Cabrita, built in the 1970s (Byrne, n.d.), which is a neighbor of this SCML unit, as shown in the image at the top of panel *Figure 4.10*.

[113] According to information available on the *MIT App Inventor 2 (n.d.)*, this extension is an altered form of "WebViewer," developed by Sunny Gupta. The extension is in its 11th version, built-in 7/13/2021.

transmitting said information to a multiple-video hosting site. Moreover, through the sharing component "Sharing_1," it enables to share the created call ID. Such sharing makes it possible for other people to have simultaneous access to the video call "room" displayed on the "CustomWebView_1."

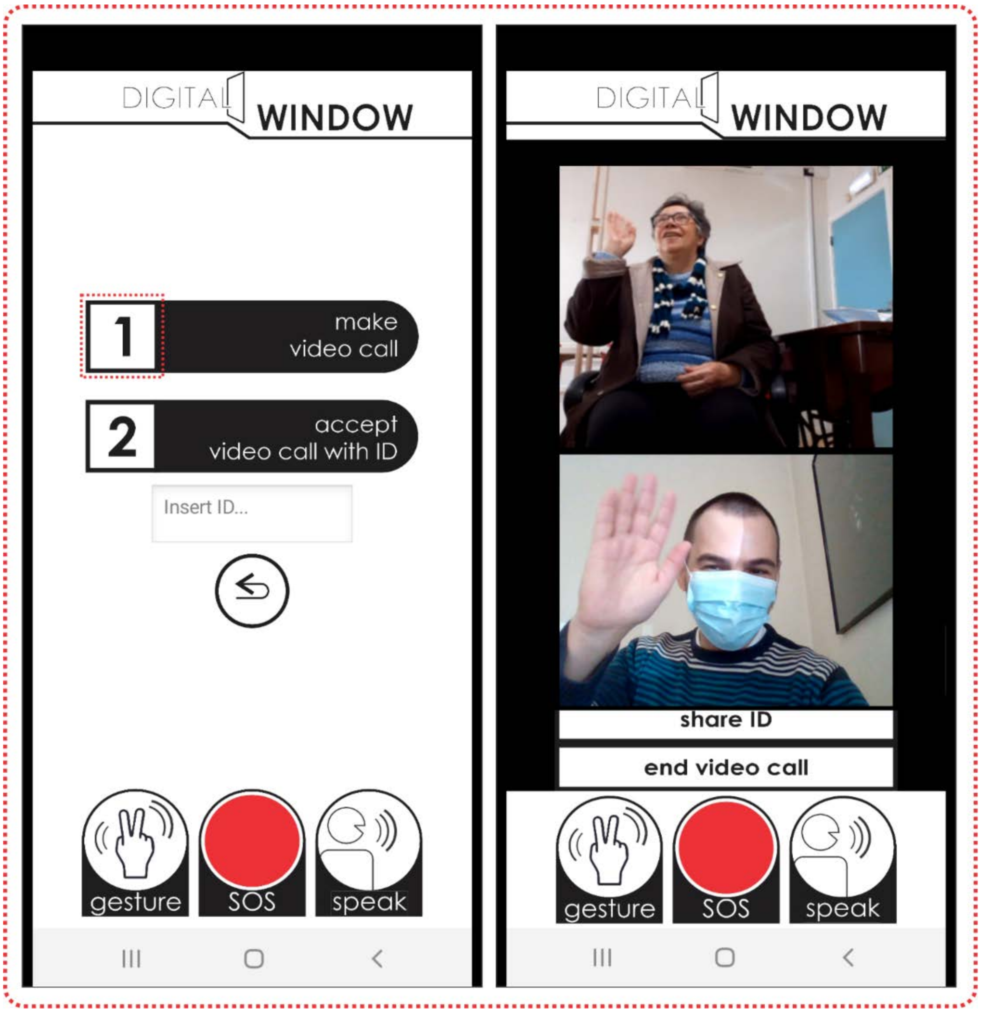

Figure 4.11 *Demonstrations of "Window 2"*

Figure 4.11 illustrated that the graphical interface changes when a video call is made or accepted. In this case, the procedure that allows performing these two actions modifies the visibility of the vertical alignments that organize these graphic elements (by "true" or "false" logic components). Once the "VerticalArrangement_1" is no longer displayed ("false"), the "VerticalArrangement_2," which contains the "CustomWebView_1," is then exhibited in the same place ("true"), allowing to visualize the video call and its closure. Accordingly, only one screen can bring together these different actions of "DW_2," even keeping the gesture and voice interaction commands and the emergency button in the same position on the graphic interface.

"Window 3"

"Window 3" is identified as the "DW_3" screen in the structured code of *MIT App Inventor* and as "see +" (see more) in the DWA GUI. Its primary function is to provide access to entertainment and research content. This window has a straightforward operation and organization. Its interface resembles "Window 1," having a horizontal organization of its content (landscape format; see *Figure 4.12*). Its programming is also supported by procedures that enable external content links to be displayed through "WebViwer" introduced in this window. Finally, a control block executes option "1" as soon as the screen is initialized.

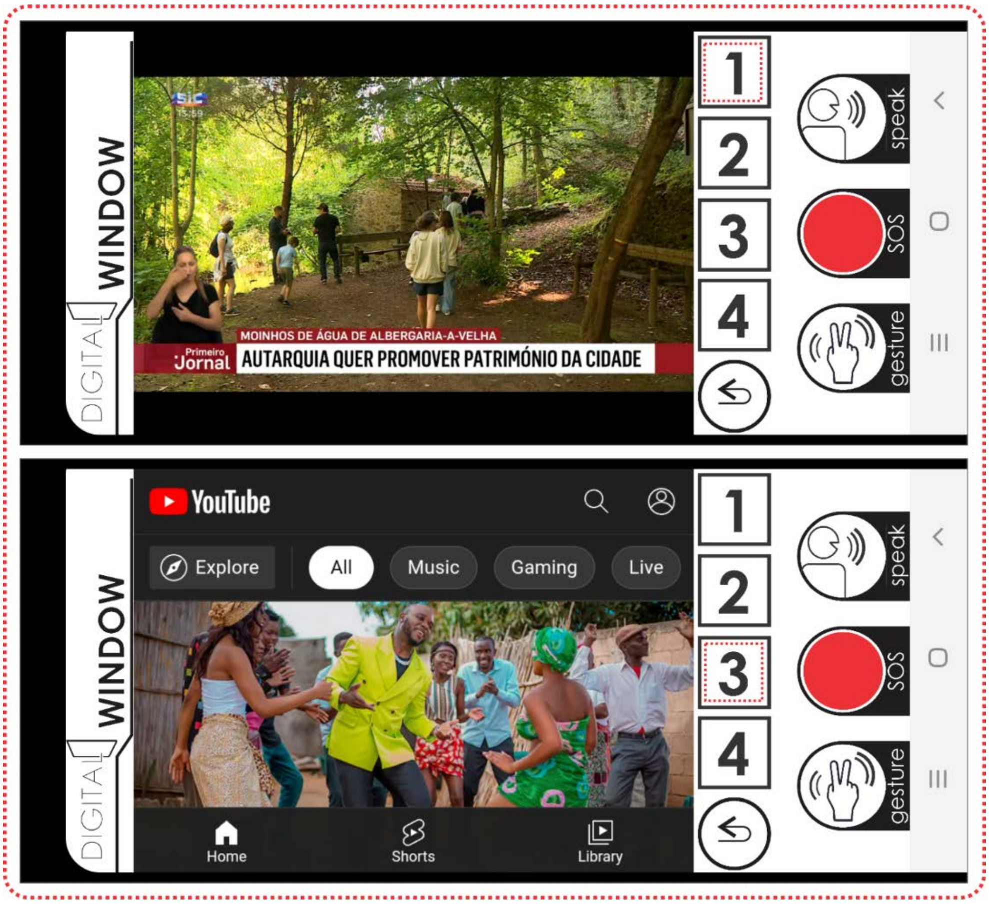

Figure 4.12 *Demonstrations of "Window 3"*

Among the four content options chosen, the first two refer to television channels known in the context of Portugal (*SIC*, exemplified at the top of *Figure 4.12*, and *TVI*). The last two options are widely used pages on the internet (the *YouTube* video viewing page, exemplified at the bottom of *Figure 4.12*, and the *Google* search page). With the live viewing pages of the television channels, an attempt was made to digitally replicate habits already established in this population cohort as a way of encouraging familiarity with the system (according to data from the DTL survey, approximately 88% of those who claimed to have a television said they saw it often, as discussed in Chapter 3).

The native web pages that are available in this “Window 3” are intended to offer access to other types of content for those that are already included digitally. At the same time, these access options seek to let the portion that is not used to digital media to remain a possibility of exploring other forms of entertainment and research when they feel more integrated with the tool. The other usage and interaction options provided on this screen follow the functionality and interface pattern established for the previous ones.

“Window 4”

Finally, there is “Window 4,” referred to as the “DW_4” screen in the algorithm and as “see themes” on the DWA graphical interface. This window lets the continuous display of images entered in the application’s algorithm (see *Figure 4.13*). The selected images are divided into two types: Those aimed at the user themself, creating a kind of digital “photo album” (option “1”) so that the user can feel more included in the application, or have their visual memories reproduced through this device; and those intended to refer to representative dates and symbols in the Portuguese context, such as referring to the national flag, the celebration of “25 de Abril,” and Christmas (option “2,” “3,” and “4,” respectively). As previously mentioned in “4.2.2 Composing the DWS” and in “3.4 *Janelar*,” these three themes were manifestations perceived with some recurrence in windows throughout the city of Lisbon.

The layout is organized horizontally (landscape mode), very similar to the “DW_1” and “DW_3” screens, with the logo image on the left and the screen on the more considerable portion (center-left). The command buttons are distributed in vertical alignment rightward; interaction and emergency buttons are further to the right. However, its algorithm does not use external links and pages as happens to the previous screens. Instead, the "DW_4" applies the display of images loaded through the *MIT App Inventor*.

***Figure 4.13** Demonstrations of "Window 4"*

In short, the operation of this function is linked to the "SLD" procedure, which changes the image displayed on the "HorizontalArrangement_2" in a controlled manner. The images that make up each of the options ("1," "2," "3," and "4") are numerically ordered, forming a list that feeds the extension "FreeImageSlider_1."[114] This extension performs image switching in animated mode, displaying each image for three seconds. At the end of the last image, the first loop will be displayed, repeating the cycle constantly until the user selects any other option in the DWA.

[114] According to information available on the *MIT App Inventor 2 (n.d.)*, this extension was developed by Narisoft Kus Zab. The extension is in its 1st version.

Tests, Reviews and Critical points of DWA development

This last function described closes the functions proposed in the DWA. Several preliminary tests and improvements were carried out to reach the final version of the application used in the “User Evaluation of DWS” test. Its development was not linear: While some features were more straightforward besides being developed without significant complexities, others—such as the video call functionality (“Window 2”) or the development of the image-based gesture recognition system—required considerable effort, many improvements, and revisions until reaching a satisfactory result, that is, the proper functioning of the intended functions.

Through the supporting application “MIT AI2 Companion”—which works as an emulator—it was possible to install the application directly on the smartphone during its development. This resource allowed the application to be tested and evaluated for each new change inserted in the algorithm programming. Hence, testing, evaluation, and review were processes in constant feedback during application development. As a result of this elaboration, the application was installed for testing 187 times until reaching its current version, used in the “User Evaluation of DWS” test, discussed in the next chapter. The development of the DWA started on March 27, 2021, and lasted until January 11, 2022, concurrently with other tasks carried out in this research.

The application development process presented limitations and solutions consistent with research conducted by a researcher in the field of architecture with no previous experience in computer science. In this sense, it is also worth noting that developing more sophisticated software and applications usually relies on a large team of developers specializing in information technology, which was not the case with the application developed here. For these reasons, some strategies adopted would not be considered coherent in a commercial context or large-scale use, for example. Nevertheless, they are justified in the context of this scientific research that aims to explore the relationship between architectural space and digital information, as said before.

Within this approach, it is relevant to mention that speech-based interaction and image recognition tools present some limitations (which will also be addressed in the next chapter). For illustration, if the user, for some reason, prefers not to use voice commands and answers “stop” to the question “what window do you want to open?” this answer ends the “listening” system (access permission to device microphones). From this moment on, the user will need to resort to touch as an interaction mechanism to be able to reactivate the voice system, if desired, since it is not possible to have a keyword that activates the system, as is the case with many operating systems available on the market. This limitation occurs because the application does not have direct access to the device microphone due to security reasons. Consequently, the microphone can only be activated by touch or in response to the “dialogue” proposed by the application when it is started or whenever it returns to “Home_Page.”

Using image recognition to distinguish gestures meets a similar but even more restrictive limitation. While some operating systems already use similar tools in facial recognition, for example (without the need to display the device’s camera in operation), DWA does not have such direct access to the camera. Therefore, to access the device camera, it is first necessary to click on the gesture recognition icon or access this functionality through voice commands. In principle, it does not make much sense to use one means of interaction to access another. However, the insertion of this method of interaction also seeks to show existing possibilities of developments in AI already available to users and demonstrate their use.

On this wise, users can realize that the manners of using the device can be multiple and, in an ideal reality, could be accessible to people with different limitations. For example: While for some individuals touch may be the most straight-forward option, for others speech may be the most appropriate method, or even gesture interaction may present a more viable alternative for them. Accordingly, the DWA seeks, even in a restricted mode, to illustrate and provide various means of interaction that suit the user’s intentions or any physical limitations, including those that may arise or be aggravated with advancing age.

Such limitations would probably not exist if this application were developed by a professional team, or by a technology company, given the technologies already developed and available nowadays. As mentioned earlier, operating systems for mobile devices (and not only) are already commonplace, managing different levels of image recognition and NLP processes. Therefore, the limitations of the DWA described can be considered circumstances and likely to be overcome in future developments or related works that start from the premises established in this research.

According to all the exposition concerning the development of the DWA, it is possible to state that the application sought to gather, through its algorithm, basic premises in the context of the DWS. The four main programmed windows configure four distinct features inspired by the *janelar* and habits verified in the DTL survey (Chapter 3). Hence, the DWA and, consequently, the DWS apparatus let the inhabitant experience the digital window concept in the context structured by this research.

4.5 Conclusion

This chapter dealt with the development of the Digital Window System in its different dimensions. This approach included the dissertation about its premises, justifications, inspirations, resources used, besides physical and abstract components explicitly designed for the operation of the DWS. The set of information necessary to arrive at the developments presented in this chapter allows understanding that it arises from the theoretical discussions and data collected and related in the three previous chapters. Finally, from these developments, it is possible to move on to the validation stage, presented in the next chapter.

In “4.2 DWS Fundamentals,” it was contextualized. Initially were presented the main goals and definitions. Then, the elements and justifications that led to the system composition were introduced. Relevant relations regarding theoretical contributions around the digital window concept also composed this section. Such relations directly impacted significant aspects of the DWS design. Subsequently, different influences from the related works were explained. Next, some data introduced in Chapter 3 and reapproached within this chapter justified the adoption of specific criteria and strategies outlined in the DWS development process. Finally, the contextualization of guidelines and definitions regarding the modes of interaction and interface adopted, namely those based on AI, occurred.

In “4.3 AI and the DWS,” it was briefly conceptualized and described the leading machine learning methods, especially those related to natural language processing and computer vision. These two fields of AI were highlighted and deepened by providing resources used as interaction tools in the DWS. The summary presentation of how these resources operate allowed a general understanding about how the DWS apparatus can statistically “see,” “hear,” and “speak” to the inhabitant, diversifying the modes of interaction with digital information.

In “4.4 Developing the DWS,” it was described and detailed, albeit briefly, the development of the necessary apparatus for functioning the DWS. This apparatus encompasses components already on the market, dynamic components created especially for the operation of the DWS, and an application developed exclusively for the DWS. The sum of these parts enables the inhabitant to experience a visualization of digital information dynamically in the domestic space, configuring a possible manifestation of the digital window concept.

It is from the prototype presented in this chapter, that is, the DWS apparatus, that it becomes feasible to carry out the test that aims to validate the hypothesis of the research, which will be addressed in the next chapter. Lastly, it is worth reaffirming that the Digital Window System was developed to configure a possibility of manifestation for the digital window concept. Through this, it becomes attainable to explore relationships among digital information, the domestic space, and its inhabitant.

4.6 References

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Evaluation of Digital Window System

[chapter]

5

Evaluation of Digital Window System

This chapter presents the evaluation of the Digital Window System and its usability. For the evaluation to become more effective, potential users performed a structured test for this purpose. The “User Evaluation of DWS” test consisted in adapting an existing space where a group of older adults tested the apparatus main features and means of interaction. In addition, systematic observation, think-aloud protocol, and application of a post-test form were also part of the methodology used to verify the DWS usability. The data obtained showed a positive evaluation and effective use of the DWS by older adults, corroborating the research hypothesis validation besides allowing to map and record paths for possible DWS improvements.

5.1 Introduction

This section of the research focused on evaluating the Digital Window System, whose development was reported in Chapter 4. The evaluation was carried out through the “User Evaluation of DWS” test. This test took place during the controlled use of the prototype by a group of older adults, as it will be described herein. In general, this chapter also details the main procedures, goals, and methods used in this evaluation stage. Finally, it presents the results and data obtained during this research phase, which are relevant instruments for validating the hypothesis.

DWS was not developed following the logic of a product for the market but as a necessary apparatus to enable the manifestation of the digital window concept. However, at this research stage, it is important to understand its dimension as a “product”[115] and, thus, be able to assess its usability. According to the definition contained in ISO 9241-11 (ISO, 1998),

[115] Here the term “product” is used in a sense advocated by Barnum (2010): “*Product* — a catch-all term to refer to any element or component of the design that contributes directly or indirectly to the user’s experience. A product can be hardware, software, a web application, or a website. It can be an e-learning course, or a company’s intranet, or a computer game, or an interactive voice response (IVR) system. It can be a print document such as a manual, getting started guide, quick reference, or assembly instructions. It can be the packaging that starts the ‘out-of-box’ experience. It can be the experience of calling customer support or engaging in a live chat session. In usability testing, the product is the ‘thing,’ or process, that is being tested.” (p. 6)

the *usability* of a product relates to the extent that it can be used by specific users to achieve specific objectives with efficiency, effectiveness, and satisfaction in a specified context. Therefore, this approach is justified by the need to use already established means and evaluation parameters, allowing to measure and verify aspects such as said usability, as well as utility, user satisfaction, and ease of use, among others (Brooke, 1995; Lund, 2001; Nielsen, 1993).

For Whitney Quesenbery (2004), five dimensions[116] allow for verifying the usability of a product ("5Es"), namely its efficiency, effectiveness, engagement, error tolerance, and ease of learning. Hence, these dimensions are part of what is observed during the "User Evaluation of DWS" test and shape much of the post-test form. However, due to the nature of the proposed use of the DWS during the test, the dimension referring to ease of learning was not investigated, but aspects related to ease of use[117] were verified, as proposed by Arnold Lund (2001).

The main objective of this evaluation stage was to be able to verify and measure the DWS usability while its target audience performed specific tasks made possible as integration of digital information with architectural spatiality emerged. For Carol M. Barnum (2010, p. 14), this objective is linked to the system validation and can be achieved through a summative test. First, though, it is appropriate to establish that the "User Evaluation of DWS" test, in addition to its summative character, also has a formative character (Barnum, 2010, p. 14). That is, it pursues the goal of diagnosing the DWS.

In the "User Evaluation of DWS" (5.2) section, the main steps, results, and discussions achieved through the homonymous test are presented, structured as follows:

[116] Quesenbery (2004) proposes these dimensions of analysis in the context of software development but indicates that they can also be applied to other contexts. Furthermore, it is pertinent to remember that a significant part of the DWS apparatus comprises the DWA, a software, as addressed in Chapter 4.

[117] Ease of use is an essential characteristic of usability and is strongly correlated with the dimension of ease of learning (Lund, 2001).

a) “Test Premises and Goals” (5.2.1): delimits the structuring dimensions of the “User Evaluation of DWS” test, characterizing its formative and summative nature, according to the classification proposed by Barnum (2010), and presents the main goals to be achieved.

b) “Test Description and Participants” (5.2.2): details description of the test, including its general formatting and procedures, as well as reporting the continuity of the partnership established with SCML (initially referred to in Chapter 3) that made it possible to carry out this stage of the research. This cooperation has a direct impact on the organization and adaptation of the space available at the Centro de Desenvolvimento Comunitário do Bairro dos Lóios (CDCBL), in Lisbon, and the profile of the 30 test participants, presented in this subsection.

c) “Data Collection Methods” (5.2.3): presents the methods employed to structure and collect test data. In particular, the methodological tools used were *systematic observation*, which consists in using controlled methods during observation (Marconi & Lakatos, 1985/2002, p. 90), the *think-aloud protocol*, seeking to stimulate the expression of the participants’ free-thinking during the scrutiny, having these data recorded (Olmsted-Hawala et al., 2010, p. 2381), and the application of a post-test form, posing questions aimed at verifying and measuring the system usability (Barnum, 2010, p. 176; Brooke, 1995; Lund, 2001).

d) “Results and Discussions” (5.2.4): based on (a) the assumptions and objectives established, this section portrays data obtained from (b) carrying out the test with the participants, and (c) the collection of structured data by the methodological tools previously discussed. These data support the positive assessment achieved by the DWS, according to information provided by the older adults who tested it. In addition, such data measure the system usability, point out usage preferences, record problems faced, and user suggestions. Finally, this information feeds the discussions about improvements that can be incorporated into the DWS in future works.

The structure proposed herein is added to the contents presented in the other chapters to configure an evaluation that seeks to validate the research hypothesis. This hypothesis—that the relationship between digital information and domestic spatiality can be beneficial to the inhabitant—is verified through the test carried out with older adults. In this context, the data consolidated in this evaluation stage support the validation of the research and indicate directions for possible evolution of the proposed system.

5.2 User Evaluation of DWS

5.2.1 Test Premises and Goals

The “User Evaluation of DWS” test arises from the need to verify how the target audience interacts with the DWS, aspiring to evaluate, validate, and improve the system. According to Barnum (2010, p. 14), a *formative test* aims to diagnose and point out ways to correct any occasional problems, while a *summative test* seeks to establish the metrics necessary for validating a product (or system).

In the formulation of the “User Evaluation of DWS” test, characteristics and tasks were gathered, enabling to configure it as both a formative and a summative test. For Barnum (2010), the test can follow the structure of a “‘Typical’ test of the product” (p. 112), with tasks that allow testing its performance and providing feedback (usually used in a formative test), as well as a test aimed at a sort of *benchmarking*, where the tasks aim to establish evaluative metrics (usually used in a summative test).

Through this test, the DWS usability was evaluated. Ergo, it verified dimensions of the DWS such as efficiency, effectiveness, engagement, error tolerance, and ease of use. According to Quesenbery (2004, p. 5), *efficiency* refers to the speed with which the user can achieve their goal; *effectiveness* refers to the usefulness and precision with which the user achieves their objective; *engagement* refers to user involvement and satisfaction with the use of the system to achieve one’s goals; *error tolerance* refers to the system ability to prevent or circumvent possible errors. In turn, according to Lund (2001), *ease of use* is related to the simplicity with which users can achieve their goals. According to Barnum (2010) and Quesenbery (2004), analyzing these dimensions allows the evaluation of the system usability as a whole. The test also sought to map specific aspects of users’ preferences concerning the functions and interaction tools available in the system.

The main goals of the “User Evaluation of DWS” test is to evaluate the DWS usability and verify aspects related to the digital window concept. The test goals are also to assess user preferences and record and examine eventual problematic points that may arise during the use of DWS by its target audience, i.e., the older adults. A final goal is to obtain recommendations about the DWS based on this opportunity of approximation with participants through their comments, made during the test (think-aloud protocol) or provided when completing the post-test form.

Therefore, the “User Evaluation of DWS” test, which consists of the experience of controlled use of the system by older adults, comes from the need to evaluate the DWS. Through this evaluation, aimed at both validating the research hypothesis and seeking to understand how users relate to the proposed system, as well as observing preferences, difficulties faced, errors, and suggestions for future improvement.

5.2.2 Test Description and Participants

The test was developed by defining the objectives and premises previously described. Its elaboration followed recommendations from Barnum’s book *Usability Testing Essentials* (2010). Finally, an imperative was to consider the particularities of both the space available for carrying out the test and the participants’ profiles (in this sense, previous experience with conducting the DTL survey with SCML was valuable).

Based on this context, the “User Evaluation of DWS” test was divided into three phases:

1) Planning: This phase started in October 2021 and ended in February 2022 after defining the space available for performing the test at the Centro de Desenvolvimento Comunitário do Bairro dos Lóios. The planning sought to structure tasks and mode of operation of the DWS to be carried out with the target audience, taking due care to stipulate tasks in an accessible language and using approaches that were close to the user, as suggested by Barnum (2010, p. 128). Scripting (and rehearsing) the test also belongs to this phase, since the initial information and instructions until the sequence of tasks and means of interaction that should be explored. Finally, a project to adapt the space for carrying out the

test was prepared (see "Appendix 5A"), to change the setting of the CDCBL meeting room so that this space could be comparable to a domestic "living room."

2) Contact with the community: Based on the link established with several SCML public service units during the DTL survey, presented in Chapter 3, the CDCBL proved to be a suitable unit for performing the test. The reasons that justify this choice include the institutional openness of the center's administration toward this research, being ready to collaborate; the large number of older adults in the community who are integrated into the center and willing to voluntarily participate in the trial (see "Appendix 5B"); and have a space available and compatible with the test needs. In order to conduct the test at the CDCBL, a new authorization was requested from the Unidade de Inovação Social e Transferência de Conhecimento in December 2021, which granted the request in February 2022.[118]

3) Execution: The execution period corresponded to one week, from March 28th to April 1st, 2022, except for the time spent in previous weeks to obtain the materials and parts necessary to assemble the support structure. The first two days were reserved for rearranging the furniture, according to the project mentioned in "1) Planning," and assembling the support structure (see *Figure 5.1*), as mentioned earlier. Such structure was wooden made and it became necessary that the swivel support could be positioned close to the ceiling without resorting to have it drilled, as the CDCBL administration imposed this condition. Therefore, the test took three days, from March 30th to April 1st. After concluding the test, it took a few hours to disassemble and reorganize the space, which happened on April 1st.

[118] Due to problems related to cases of COVID-19 infection among users of the Center, SCML requested that the test be carried out from March 2022.

Following Barnum's recommendations (2010, p. 252), the test was carried out face-to-face with 30 participants (see *Figure 5.2*[119]), a number that the author considers as suitable for tests of this nature. The list casting the 30 participants can be consulted in "Appendix 5D." In addition, in "Appendix 5B" gathers copies of the authorization terms for data registration signed by each participant. These documents also include the exclusivity term signed by this researcher, committing to use the test data and the image of the participants within the context of this research only.

The CDCBL administration selected all participants, and the only requirements made to the center to guide this selection were that participants be 65 years or older and have cognitive ability compatible with the test. Participants were not required to have previous experience with digital media, to be literate, or to have no physical limitations. Thus, some participants had physical disabilities (mainly motor, auditory, and visual). Besides, there was a small portion of illiterates among participants, many of them not being used to digital media. However, these facts did not prevent volunteers from taking part in the test.

Test population average age was 77.73 years, the youngest participant counting 66 and the oldest being 89. Regarding gender, 70% among participants were female (21 individuals), while 30% were male (9 individuals). Notably, this gender distribution is relatively close to that of participants in the DTL survey (76.4% female and 26.3% male). Moreover, such data are not so dissonant when compared to those recorded in the "2021 Census" and provided by INE (2021b). This data point to 61.5% of women and 38.5% of men in this age group in Lisbon (as discussed in Chapter 3).

The test was conducted with one participant at a time, always accompanied by this researcher. The test lasted approximately 20 minutes for presenting and performing its tasks and other 10 minutes to apply the post-test form ("Appendix 5C"), totaling approximately 30 minutes per participant. Thus, around 900 minutes (15 hours) were consumed for testing and applying the form to all 30 participants. This time it was non-linearly divided over the three test days, according to participants' availability as well as CDCBL's opening hours.

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[119] *Figure 5.2* is a panel formed by the portrait of the test participants. However, one participant preferred not to be photographed, which was promptly accepted, thus this is the reason why the panel consisted of 29 portraits.

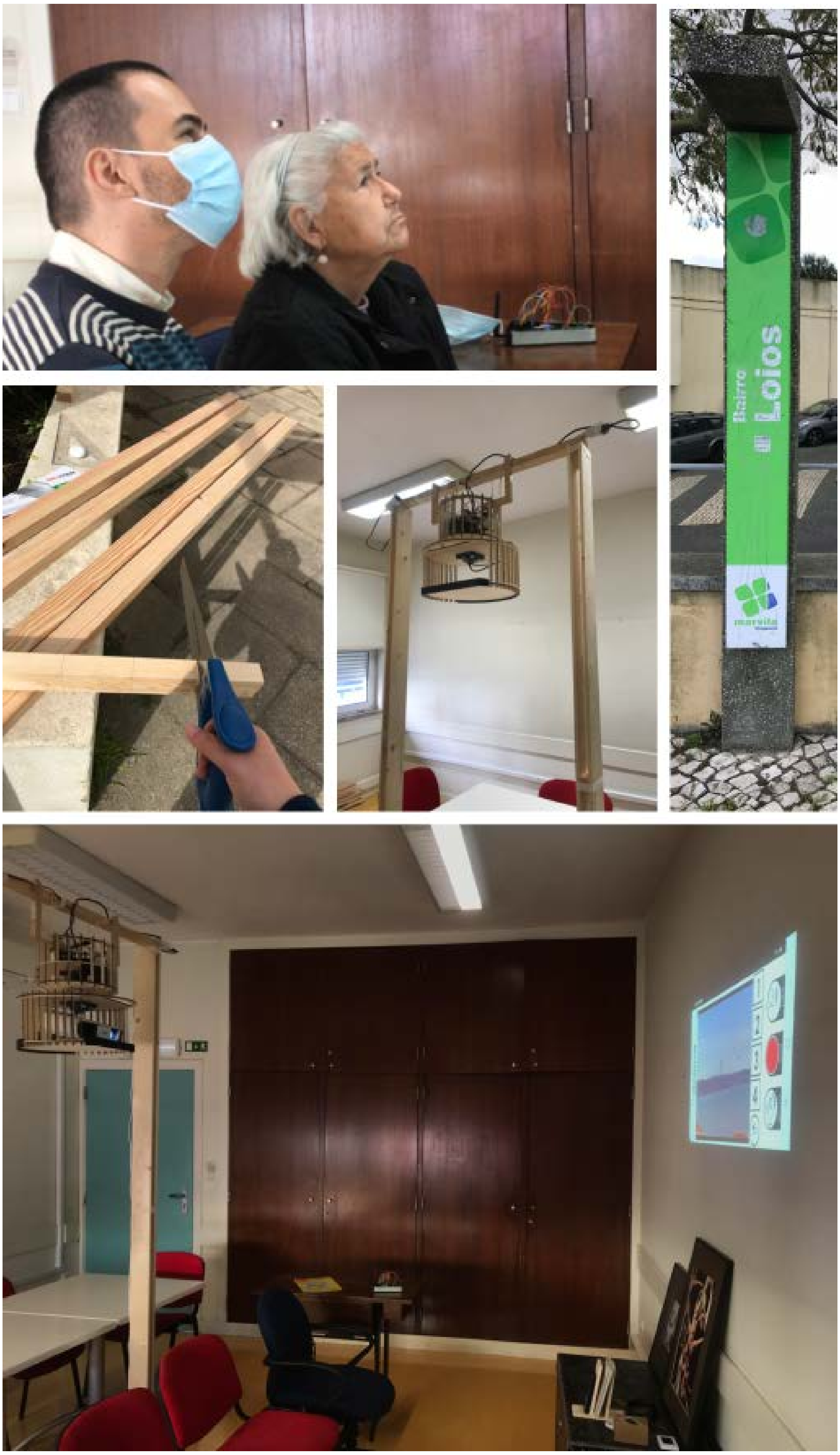


Figure 5.1 *Assembly, spatial organization, and test execution*

Figure 5.2 *Participants*

The stages and tasks that make up the test followed the recommendations of Barnum (2010, p. 128) and Nielsen (1993, pp. 185–187) and were structured in five stages, described as follows:

1) *Stage 1*: Opening the app and consequent activation of the DWS apparatus. In this procedure, while the initial animation was displayed, the movements of the swivel support projected the digital information through space, as described in Chapter 4. This step took 30 seconds and allowed the participant to realize that they were free to modify the positioning of the projection.

2) *Stage 2*: It consisted of a short introduction that briefly covered the development of DWS, the digital window concept, and an overview of the test. Such presentation took approximately three minutes. It is relevant to report that part of this initial speech was to clear up any doubts participants might have, highlighting that the DWS was under evaluation, not the participant. Meanwhile, participants were also encouraged to express their opinions throughout the test, whenever they deemed it appropriate, pursuant to the think-aloud protocol.

3) *Stage 3*: Performing tasks “W_1,” “W_2,” and “W_4.” Each of these tasks consisted in triggering the functions of specific windows (“Window 1,” “Window 2,” and “Window 4,” respectively). In the “W_1” task, the participant had to access, via voice command, two different cameras, initially camera 1 (with external images in real-time) and then any of the other options (two cameras in Lisbon and one in Madeira Island). During the “W_2” task, the participant should make a video call (as can be seen in *Figure 4.11*, in the previous chapter), and they should use touch as a means of interaction since this is a means of interaction more conventional and this is a relatively more complex task than the others. For “W_4” task, participants should use the gesture recognition interface to access the first image gallery (with images of CDCBL users previously made available by the center administration) and operationalize the issuer control to change the projection positioning, turning it to the opposite wall.[120]

[120] This change of position was planned for this particular wall because it is favorable (no window, no fixed furniture, and different from the wall where the projection was already located until this

4) *Stage 4*: To carry out task "W_3" (referring to "Window 3"). This one happened in isolation from the previous tasks because it was a task that had its execution time measured. Such record (systematic observation) helped to verify the DWS efficiency. In this task, participants should use voice command to access "Window 3" and, within it, access channel two; later, return to the initial menu.

5) *Stage 5*: Activate the emergency call command[121] by using all three means of interaction (touch, voice, and gesture). In the first simulation, participants were instructed to tap the red button on the graphical interface, which generated the emergency call. During the second simulation, the participants called "help" or "emergency," for example, with the voice command activated. Finally, for the third simulation, participants were instructed to have image recognition activated while raising one of their fists closed, which also caused the DWS to perform the emergency call.

This set of activities, developed in a structured way, sought to give participants an overview of the possibilities offered by the DWS, its functions, and means of interaction. On the other hand (and more importantly in the context of this research), these tasks and stages allowed the establishment of a system evaluation by users and the application of appropriate methodologies for data collection. Such data support the assessment, discussions about the DWS, and possible improvements. Therefore, consecutive to executing this set of activities, the post-test form was applied, which will be discussed throughout the following sections.

moment); and because it allows the participant only to turn the chair where was already seated (participants were instructed to always sit in the same chair, which swiveled). In this way, more prominent movements were unnecessary, which could be difficult for those who eventually had reduced mobility.

[121] In the DWS algorithm, the number saved as an emergency is 112. However, as it was an emergency simulation, in the test, the emergency call was made to the number +351 912 646 537 (a private number) from the number +351 914 104 706 (number for the exclusive use of this research).

5.2.3 Data Collection Methods

In addition to the methodology applied to develop the "User Evaluation of DWS" test, an array of methodological instruments was selected to systematize and facilitate the collection of data resulting from the test. The three methodological instruments used were systematic observation, think-aloud protocol, and the application of the post-test form. Despite being independent, these three methods were established in a coordinated and complementary manner, aiming to consolidate a cohesive data set.

According to Marconi and Lakatos (1985/2002, p. 90), *systematic observation* is a structured observation carried out in a planned context, using instruments for data collection. This type of observation was performed on two occasions throughout the test, with the registration of the number and type of possible system errors and during the performance of the task "W_3," in the fourth stage of the "User Evaluation of DWS" test.[122] In this last task, it was necessary to use an electronic chronometer-type instrument to verify the time spent (measured in seconds) for accomplishing the task by each of the 30 participants. This data is significant because, according to Barnum (2010, p. 11), measuring the speed with which the user can perform a task is a way of verifying the efficiency of a system, one of the dimensions of usability.

The think-aloud protocol is understood by Nielsen (1993, p. 195) as one of the most important methodological instruments for evaluating the usability of a system. The *think-aloud protocol* consists in encouraging participants to verbally express their ideas while performing the tasks or test steps and for the researcher to record this information (Ericsson & Simon, 1993, p. 216). Different approaches and stimulation levels get participants to express themselves during the test (Olmsted-Hawala et al., 2010, p. 2384). This research adopts the version classified as "Traditional" by Olmsted-Hawala et al. (2010). This protocol was developed by Ericsson and Simon (1993) where, initially, it is necessary to instruct participants to

[122] The data obtained through systematic observation are included in "Appendix 5D" alongside the data from the post-test form, with the notice that this researcher measured them.

express themselves verbally during the test, but without using stimulus questions throughout it.

Even though a considerable number of participants did not speak their thoughts during the test (which is generally expected in this type of method, according to Barnum [2010, p. 206]), relevant contributions were recorded (see "Appendix 5E"). This method was advantageous to check possibilities for system improvement and understand why participants were interested or not in certain functions (which will be further discussed in the next section).

The post-test form ("Appendix 5C") was prepared following Barnum's recommendations (2010, p. 176), mainly concerning the care with the question elaboration so that they are clear and linked to the test goals. As mentioned earlier, Quesenbery (2004, p. 5) provided the main dimensions of usability encompassed in the form, and Lund (2001) reinforced the importance of the dimension "Ease of use." The guidelines followed, both to elaborate the questions where the evaluation scale was used and in the form extension, were based on the SUS – System Usability Scale (Brooke, 1995) and USE – Usefulness, Satisfaction, and Ease of use (Lund, 2001).[123]

Accordingly, the form was divided into four sections: The first section aimed to identify participants; the second to evaluate the usability of the DWS; the third to evaluate the DWS usage experience and usage preferences; the fourth section was devoted to the problems faced and suggestions for improvement. Excluding the required information regarding the identification of the participants (such as name, age, and date of the test), the form was proposed with 20 questions, 18 of which were objective, an open question, and a field for recording possible system errors.

Among the 18 objective questions, eight aimed to measure effectiveness, ease of use, engagement, and more specific aspects related to the digital window concept. Following Brooke's recommendations (1995), the answers to those eight questions used the *Likert scale*, where the participant

[123] It is significant to delimit that both questionnaires served as a basis for preparing the post-test form, but neither was fully adopted, as they did not encompass the specifics and idiosyncrasies of the evaluated system.

indicated the alternative that best represented their degree of agreement or disagreement with the statement on a five-point scale.

Subsequently, 10 objective questions were inserted that sought to map users' usefulness, satisfaction, and preferences among the main functions provided by the DWS, as well as their means of interaction. In those questions, the participants chose a function (or means of interaction) to the detriment of the others, always having the option to choose "none of these" as an answer. Ultimately, the final question was open, where participants could make suggestions for improvement. The answers obtained through this open question, with some frequency, shaded data already collected in the think-aloud protocol. This possibility had already been predicted by Barnum (2010, p. 258).

Through these three methodological instruments, it was possible to collect data from the "User Evaluation of DWS" test in a structured and comprehensive way. In this sense, it was feasible to evaluate the system usability, verify questions regarding the digital window concept, and map participants' preferences concerning the DWS. Finally, the data obtained supported the discussions and the analysis of the results in relation to the test goals, as discussed below.

5.2.4 Results and Discussions

This section presents the results of the "User Evaluation of DWS" test, using data collected following the methodological instruments discussed in the previous section. Along with the presentation of the outcomes, discussions about the evaluation of the system usability, its relationship with the digital window concept, and user preferences emerge. Such discussions seek to validate the hypothesis through the evaluation of the DWS and point out ways for future system improvements based on the information gathered through the test.

The data obtained are of different natures and present a qualitative bias (Guerra, 2012) and a quantitative bias (Barreiros, 1984; Nazareth, 1981). The presentation of results uses simple statistical instruments, depending on the character of the variables studied. Data can be expressed numerically through the presentation of means, standard deviation, besides minimum and maximum values; in other cases, through percentages (Barreiros, 1984). Such data are still illustrated with the presentation of surface graphs in columns (Marconi & Lakatos, 1985/2002, p. 199) and pie charts of sectors (pp. 202–203) which, occasionally, are presented within this text but are available in their entirety in “Appendix 5D.” The questions using the five-point Likert scale (Barnum, 2010, p. 180) are presented in this section in the format (Mean; Standard deviation), and the other multiple-choice questions are presented in this section in the format (Number of participants; Percentage).

Some information from the application of the think-aloud protocol (Ericsson & Simon, 1993) is cited herein. Additionally, the entirety of the comments can be consulted in “Appendix 5E,” mentioned earlier. Both these comments and all data referring to the test were originally produced in Portuguese, in accordance with the participant’ mother tongue (all Portuguese). However, for clarity and consistency with the writing language of this research, they are expressed in U.S. English.

The data requested in the first section of the post-test form refers to the participants’ identification and has already been presented in “5.2.2 Test Description and Participants.” The second section, identified as “Evaluating the DWS Usability,” presents both data resulting of direct observation carried out[124] as well as data collected through questions answered by the participants, seeking to evaluate effectiveness, engagement, and ease of use of the DWS.

Regarding efficiency, measured by the performance in task “W_3,” all participants were able to complete the task, but the time spent to perform it ranged from a minimum of eight seconds (participant P09) to a maximum of 49 seconds (participant P27), as evidenced by the graph shown in *Figure 5.3*. It also displays that most participants (18; 60%) took less time than the average time of all participants (23.1 seconds). Furthermore, a minor part of the participants (12; 40%) had a time greater than the average, and, out of

[124] Measurement of time to perform task “W_3,” the number of errors, and type of errors observed during the test.

those, only four (13.3% of the test population) took more than 35 seconds, generating the significant standard deviation verified (10.87).

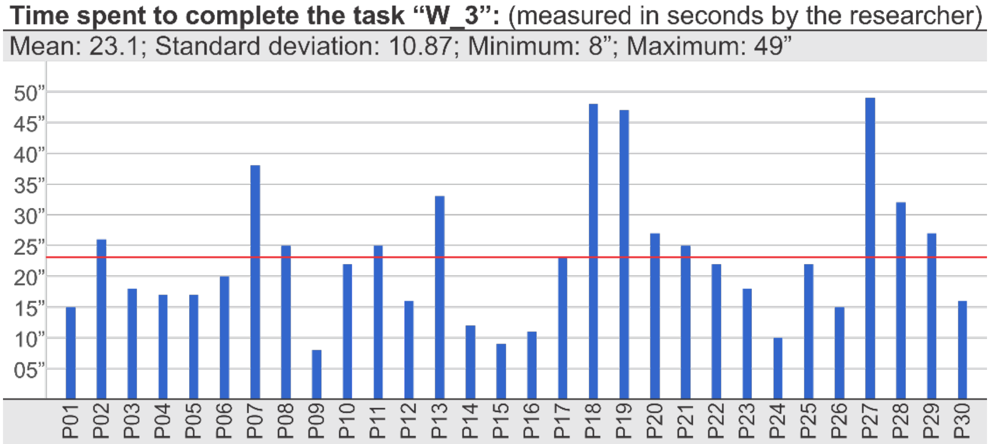


Figure 5.3 *Measurement of time spent to perform task "W_3"*

In general, it is possible to affirm that participants used the tool efficiently since most of them could perform the requested task in a shorter time than the average. However, the significant differences in the speed for completing the task "W_3," among several possible factors, may be related to the difficulty some participants faced with using the means of interaction by voice command. The three participants (P18, P19, and P27) who took more than 45 seconds to perform the task were the participants who witnessed the highest number of system errors (P18 had three errors, and P19 and P27 had two errors each). Here it is relevant to delimit that when the system did not correctly identify the words spoken, this was understood as a system error and, therefore, recorded.

Regarding the errors presented by the DWS, including those verified during the performance of the "W_3" task, 12 errors were recorded during the entire test. The errors affected eight participants (26.7%) and were concentrated on two occasions: failure of speech recognition (10 times) and failure of the image recognition system used for gesture interaction (twice). Even if it is a considerable number of errors, the fact that they are concentrated on these two specific activities facilitated the identification of trouble spots.

As for image recognition, in "4.4.3 Digital Window App," it was already mentioned that the image recognition system could evolve by inserting a more extensive and diverse database, which probably could help reduce the frequency of this error type. As for speech recognition, three errors (30% of speech recognition errors) happened due to fluctuations on the internet connection. Speech recognition is performed by an extension that works online only. On the other hand, most errors in speech recognition (70%) occurred due to users' difficulty or lack of habit in speaking intelligibly and at an appropriate volume to the system.

Regardless, it is important to mention that, in general, it is not the users who must speak in a way that the system can understand them. In an ideal situation, it is the system that needs further refinement to be able to perform more inclusive speech recognition. As such recognition is made by an extension from *Google* company, made available by *MIT App Inventor* (2020), it is likely that constant evolutions will be sought.

When asked how effective the use of the DWS had been in the post-test form (see *Figure 5.4*), it is possible to affirm that, in general, participants considered their experience effective (4.03; 0.94). The vast majority opted for the options "effective" (9; 30%) and "very effective" (12; 40%). This positive perception probably stems from the participants' ability to perform all the proposed tasks. It is important to remember that the use of the system was guided, with this researcher guiding them throughout the use and being available to provide help whenever necessary.

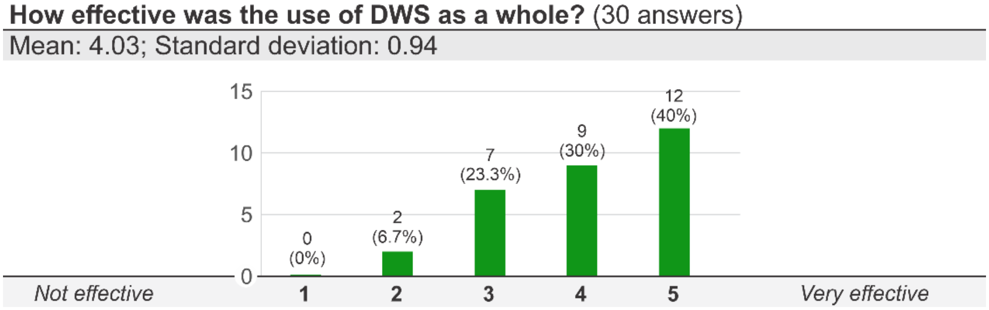
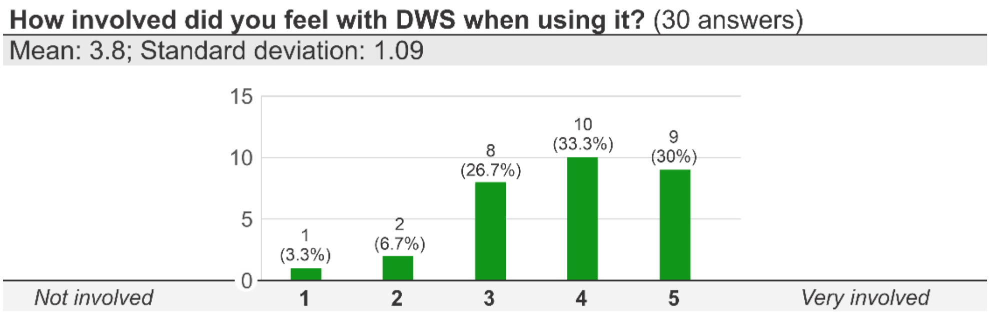


Figure 5.4 *DWS effectiveness assessment*

Still, in evaluating other usability dimensions (see *Figure 5.5*), it is possible to affirm that participants felt relatively engaged with the DWS while using it based on the average response obtained (3.8; 1.09). Even though the majority felt "very engaged" (9; 30%) or "engaged" (10; 33.3%), a considerable number of participants felt "neither engaged nor disengaged" (8; 26.7%).

Regarding the ease of use of the system, the numbers indicated that the DWS was considered, on average, a system that is neither easy nor difficult (3.43; 0.88). Despite the majority classifying the use of the system as "easy" or "very easy" (16; 53.3%), an expressive number of participants classified it as "neither easy nor difficult" (10; 33.3%), and a minor number part judged the use of the system as "not so easy" or "not easy" (4; 13.3%).



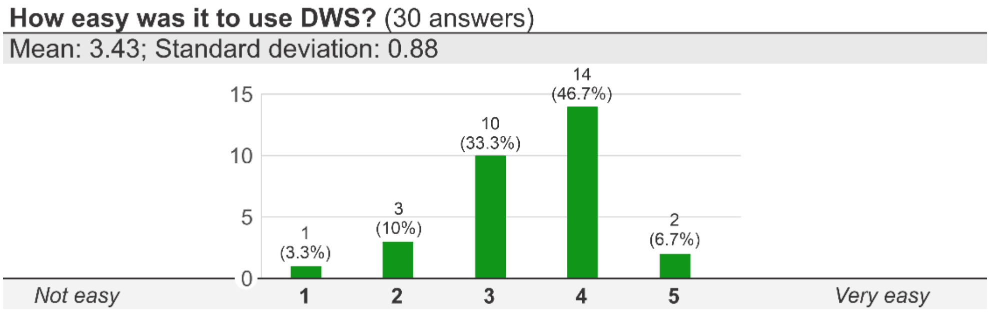


Figure 5.5 *DWS engagement and ease of use assessment*

Some participants who did not feel engaged with the DWS expressed opinions such as "*I do not see the need for this type of equipment*" (Participant P04). Among those who found the use of the system "not easy," participant P19 expressed as a possible justification for his evaluation the fact that he did not have a cell phone or computer and he only had the habit of watching television, mentioning that "[I] *do not understand any of this technology stuff*." This statement is a commonplace when older adults feel digitally excluded, and that can evidence the occurrence of technophobia[125] (Ha et al., 2011). Such positions, in general, help to justify the median evaluations obtained in the questions related to engagement and ease of use of the DWS.

[125] Joong Gyu Há, Tom Page, and Gisli Thorsteinsson (2011) define technophobia as fear, aversion, or anxiety provoked by contact with new technologies (p. 17). Although this phenomenon manifests in all age groups, the authors state that its occurrence is more pronounced in older generations (p. 19).

In the third and most extensive section of the "Evaluating the Experience of Using DWS and Preferences" form, 15 questions were inserted, seeking to evaluate aspects related to the digital window concept, system utility, preferences between different functions (windows), and means of interaction. The first of these questions sought to assess whether DWS could improve the quality of time spent at home. It is noteworthy that such question arises from approaches proposed in Chapter 1, like the concept of AiP and data collected from the DTL survey (presented in Chapter 3). Both approaches relate to a significant amount of time spent indoors by this part of the population. Elizabeth Burton et al. (2011), already cited in Chapter 3 and Chapter 4, stated that older adults are the portion of the population that spends more time indoors.

As illustrated by the graph in *Figure 5.6*, one can discern a convergence within most participants regarding the possibility of the DWS improving the quality of time spent at home (3.86; 1.14). Among them, the vast majority "agree" (12; 40%) or "strongly agree" (10; 33.3%) with this statement. Such an assessment is highly positive within the ambitions motivating the DWS development, showing the existence of a gap where approaches of this nature may be relevant. This result contributes to evidencing the relationship between domestic space and digital information as beneficial for the inhabitants. Furthermore, within the specific context of this population age stratum, this data reveals that DWS can improve the quality of time spent at home by older adults.

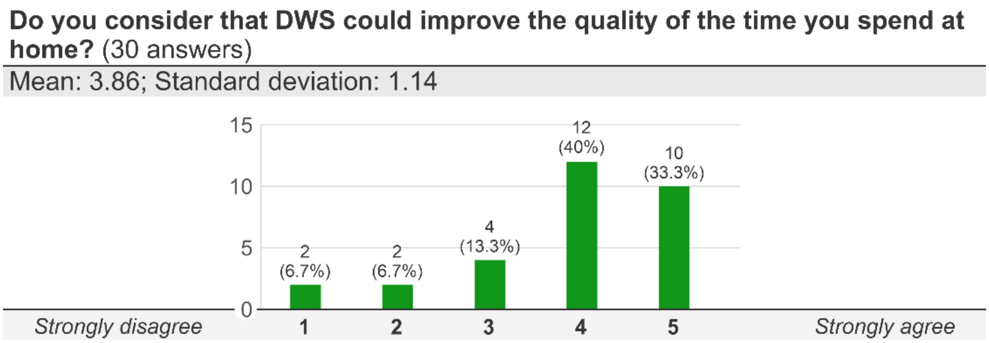


Figure 5.6 *DWS assessment in the face of improvement in time spent at home*

Most participants also considered that the DWS could facilitate internet use at home (3.96; 1.25). The aggregate of those who "agree" (8; 26.7%) or "strongly agree" (14; 46.7%) with this possibility totaled 73.3% among participants. The same proportion was verified when they expressed the possibility of the DWS facilitating communication with friends, family, or institutions (4.03; 1.13). In this way, the data obtained indicate that the participants evaluate the DWS as a facilitator of internet use at home and as a communication tool. In this context, it is worth remarking the favorable mention referring the possibility of communication offered by the DWS, made by participant P09: "*It is good to be able to make large video calls*."

The fact that most of participants consider that the DWS can improve the quality of time spent at home, facilitating internet use and communication with family, friends, and institutions is a very positive assessment. In this sense, it is noteworthy to remember that digital inclusion of older adults is still an objective to be achieved (Betts et al., 2019). During the "*Simpósio Interações - 11ª Sessão - Envelhecer na Era do Digital*," speaker Paula Guimarães (2021) pointed out digital inclusion as an element that would bring benefits to this segment of the population. Therefore, the DWS proves to be a relevant tool in this process and highlights the potential of the relationship between digital information and domestic spatiality as a facilitating factor along this process.

Another significant finding measured in the post-test form was that most participants (4.13; 1.23) considered the dynamic aspect of the DWS important for their domestic use (see *Figure 5.7*). The sum of those who "agree" (6; 20%) or "strongly agree" (17; 56.7%) with this possibility totaled 76.7% of the participants. This high proportion indicates that participants found the mobility aspect of digital information visualization related to domestic spatiality as beneficial. Such verification is relevant for the digital window concept defended herein and for validating the work hypothesis as a whole, once it shows in an even more direct way that the relationship involving digital information and the architectural space can enhance inhabiting and bring benefits for the inhabitant.

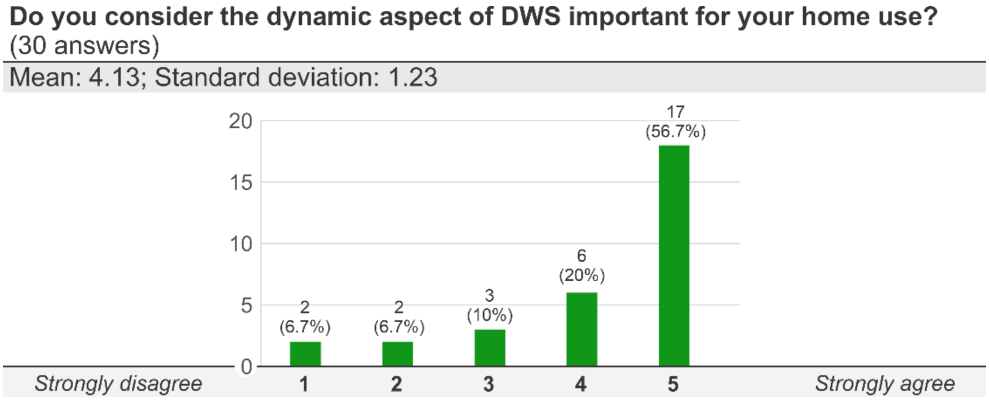


Figure 5.7 *Evaluation regarding the dynamic aspect of DWS in relation to its domestic use*

When asked if they considered that the DWS could be a useful tool in their daily routine, most participants indicated agreement (3.56; 1.28), though this agreement was less emphatic when compared to the question illustrated in *Figure 5.7*. The sum of those who “agree” (11; 36.7%) or “strongly agree” (8; 26.7%) with this possibility totaled 63.3% of the participants. Therefore, if the comparison with data from the previous question is maintained, one can see that participants considered aspects of the tool relevant (namely, the dynamic aspect of the DWS) while generally still not seeing its usefulness with the same strength. Such data may be motivated by many factors, including the nature and brevity of the test, which did not allow for continued use, where participants could have the opportunity to develop a more in-depth usage relationship with the system.

Regarding user preferences, according to Barnum (2010), an effective way to map them is to resort to simple, direct, and—depending on the context—antagonistic questions. These recommendations were incorporated during the post-test form preparation (as mentioned earlier). The data collected are presented in sequence. Such data seek to show which features (among “Window 1,” “Window 2,” “Window 3,” and “Window 4”) and means of interaction (gesture, touch, and voice) were the most and least appreciated ones.

Participants were asked to choose the window (function) they liked the most and the one they liked the least (in both questions it was possible to choose only one answer). As shown in *Figure 5.8*, participants chose “Window 1” (12; 40%) and “Window 4” (8; 26.7%) as their favorite windows, respectively. Regardless, when the question is inverted, the answers were relatively scattered among the four windows, being predominant the answer “None of these” predominated (11; 36.7%). This prevalence may indicate that, in general, the functions offered by the DWS through these windows were well tolerated by the participants.

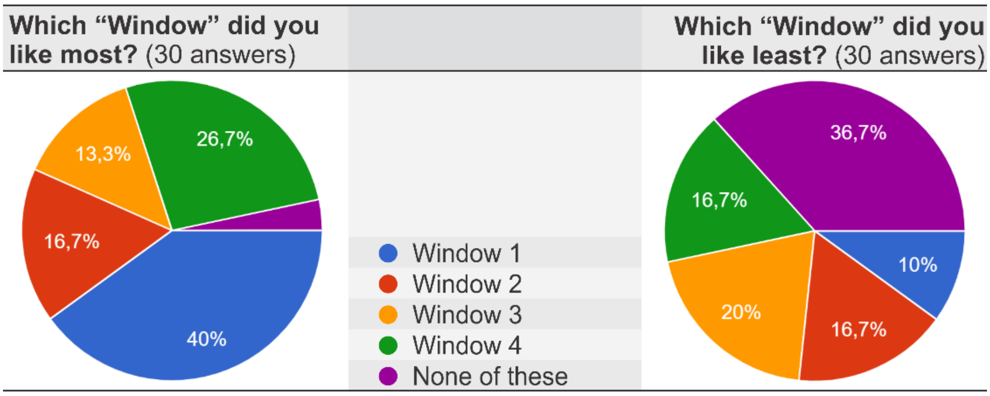


Figure 5.8 *Result of preferences among the main functions*

Still, on the options chosen as the ones that most pleased the participants (“Window 1” and “Window 4”), it is possible to speculate that these preferences may have arisen from the ease of access to the information available and its nature. Regarding the ease of access to information, “Window 2,” for example, has a use that requires more operational steps. Concerning the nature of the information offered by the windows, it is relevant to verify that both “Window 1” and “Window 4” offered less usual content and, in a certain analysis, more particular to users. In this sense, it is worth remembering that “Window 3” either reproduces television channels already available on the television set or needs to be used with more steps to explore more specific and personalized content.

The information presented in *Figure 5.9* helps to support part of the argument in the previous paragraph. The questions that aimed to investigate which windows were easier and more difficult to use revealed that, precisely, “Window 4” (10; 33.3%) and “Window 1” (9; 30%) were pointed out as the easiest to use, while “Window 2,” was identified by a large majority (18; 60%) as the most difficult one.

In this context, most likely, the number of steps necessary to reach the functionalities in question must have been the determining factor for the participants’ judgment. As mentioned before, “Window 2” requires a considerable number of steps, while “Window 4” and “Window 1” require a few steps. In a way, it is also possible to include “Window 3” in this reading. “Window 3” was identified as the third easiest window to use (8; 26.7%). As previously stated, “Window 3” requires a few steps to access television channels in direct online transmission. However, the number of steps grows if the user prefers to perform internet or video platforms search.

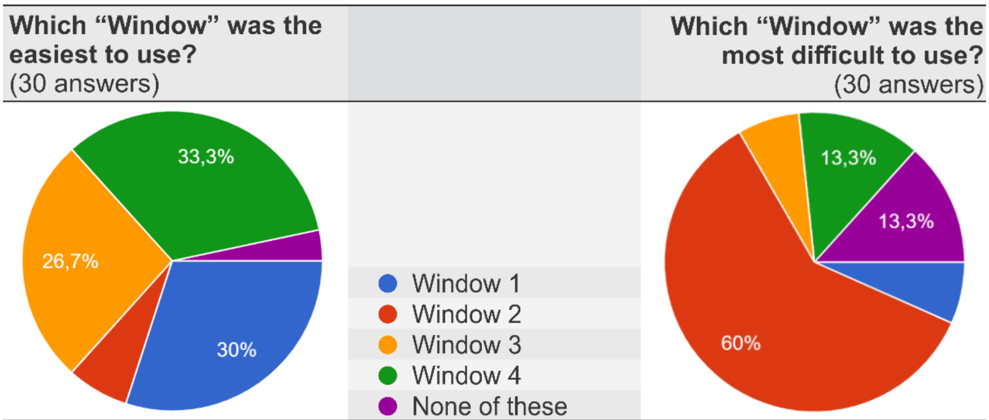


Figure 5.9 *Result about the ease of use of the main functions*

As for the usefulness of the functions offered by the DWS through its windows, participants chose “Window 3” (14; 46.7%) as the most useful, followed by “Window 2” (8; 26.7%), as can be seen in *Figure 5.10*. This option can eventually be justified by the fact that these windows allow the performance of already established functions, such as watching television and making video calls, respectively. It is worth remembering, for example, that in the DTL survey, 98.9% of the sample said they lived in a dwelling with a television, and among these, 87.9% claimed to watch television frequently, as shown in Chapter 3.

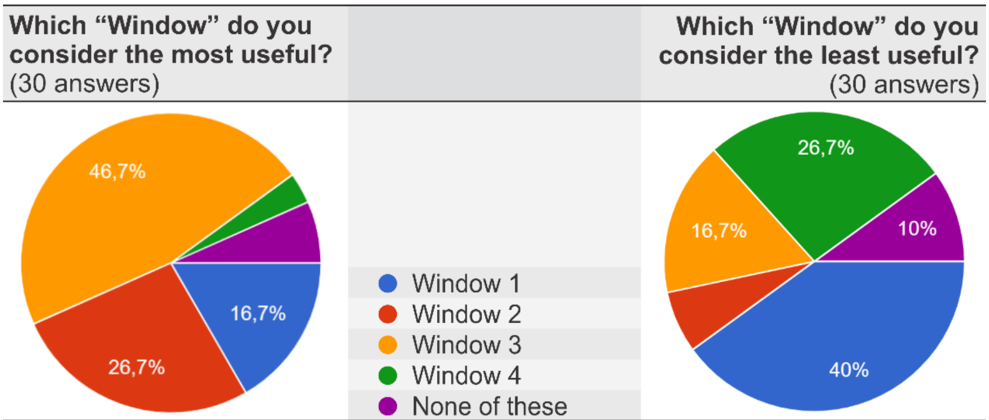


Figure 5.10 *Result about the usefulness of the main functions*

In contrast, “Window 1” (12; 40%) and “Window 4” (8; 26.7%), respectively, were considered the least useful by the participants. Such choices can arise either because they are less common or have more contemplative functions without significant practical implications. However, here one could perceive an independence between what participants find useful and what they consider preferable since these two functions were also chosen as the ones that participants liked the most (as seen in *Figure 5.8*).

Concerning the means of interaction, participants were first asked to choose the means of interaction they liked the most and then the one they liked the least (see *Figure 5.11*). In both questions, it was possible to choose only one alternative. When asked which means of interaction they liked the most, participants chose the means of interaction by touch (12; 40%) as their preferred one, followed by gesture (10; 33.3%), voice (8; 26.7%) interaction. Regarding the means of interaction that the participants least liked, there was more balance among their answers, with the interaction mediated by voice being the one that was chosen as the least liked (10; 33.3%), followed by gesture and “none of these” (7; 23.3), and, finally, touch-mediated interaction (6; 20%).

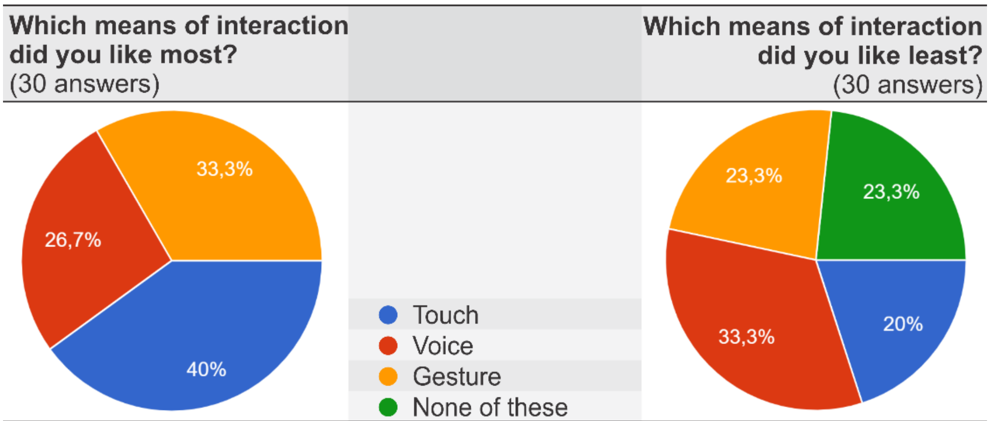


Figure 5.11 *Result of preferences among the means of interaction*

Even though the data point to a certain equilibrium regarding preferences, one can notice that the touch interaction mode was both the favorite and the least displeased for participants. This occurrence may be due to this being an already widespread means of interaction, with which a considerable part of the test population was, after all, accustomed.

The means of interaction by gesture was relatively well-rated. This positive evaluation may be due to a certain aspect of novelty and discovery demonstrated by some participants not used to this type of artificial intelligence resource. For instance, it was evidenced by the testimony of participant P22 when she said: "*How funny it is to know how many fingers I am getting up.*" On the other hand, the negative evaluation may be due to recognition errors (already mentioned) and the fact that some people do not feel comfortable having their image used by the device.

The interaction means based on speech recognition was evaluated as the one that participants liked least. This fact is possibly a result of frequent errors in speech recognition, as previously remarked. Nonetheless, it is also relevant to mention that not all participants were used to talking with a system of this nature, which may cause awkwardness or discomfort in an initial moment.

Given the relative balance mentioned above, it is possible to affirm that the evaluations demonstrate the assimilation of the means of interaction by touch among the participants and an opening to other interaction possibilities. In this context, the gesture recognition alternative offered by the DWS proved to be promising, reinforcing the role of AI as an approach that can be useful to this interaction process between domestic space and digital information.

The last questions on means of interaction sought to assess which means participants found the easiest and most difficult to use (see *Figure 5.12*). In this context, touch was chosen as the easiest means of interaction to use (18; 60%), followed by voice-mediated interaction (7; 23.3%) and gestural interaction (5; 16.7%). As for the opposite question, voice interaction was considered the most difficult to use (13; 43.3%), followed by gesture-mediated interaction (11; 36.7%), "None of these" (4; 13.3%), and, finally, touch interaction (2; 6.7%).

Many points discussed earlier can also be indicative of the evaluations obtained from these two questions. The fact that the majority considered touch-mediated interaction the easiest (also the least difficult) may be due to this being the interaction type with which most participants may have already had contact or been used to interact. Even though voice interaction was identified as the second easiest to use, most participants also chose it as the most difficult to use, probably, partly due to system errors. In this sense, the difficulty of the system understanding regarding what was said by the participants was verified 10 times, with six of them. All these participants are among the 13 who chose this means of interaction as the most difficult to be used (see “Appendix 5F”).

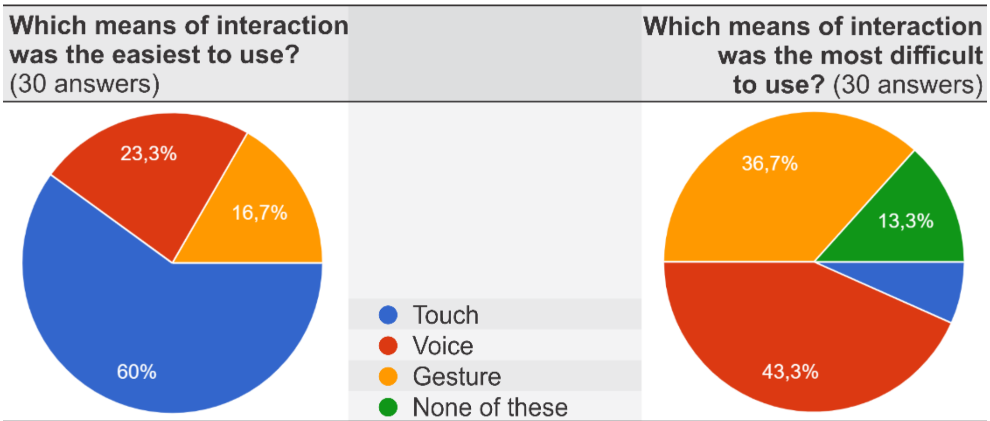


Figure 5.12 *Result about the ease of use of the means of interaction*

It is also worth remembering, as reported in “*4.4.3 Digital Window App*,” that because of the development limitations faced in this research, both voice and gesture interaction required an initial click on their corresponding icons, generating an extra step for using them. Additionally, this fact can generate a sense of pointlessness since it is necessary to resort to an interaction method to access other methods. The participants, even knowing it is a system still under development and part of an academic research, are not always aware of the theoretical implications and limitations of development regarding the system to which they were presented (and tested by them).

An interesting point to discuss relates the diversity of interaction means as intended to be an alternative in the face of possible limitations arising from the natural aging process or even physical limitations with which users occasionally live, as mentioned in Chapter 4. For example, among the 30 test participants, none lived with a situation of blindness, deafness, or total muteness. However, it was common to observe that many showed some degree of limitation, especially concerning vision or hearing. Accordingly, it is possible to conjecture that the diversity of positive (and negative) evaluations regarding the means of interaction by touch, gesture, and voice may reflect that, depending on the nature of the limitation faced by each participant, one means of interaction may have proved more accessible and more pleasant than another (see *Figure 5.11* and *Figure 5.12*).

In the fourth and last section of the form ("Problems and Suggestions") the errors found during the test were recorded, and an open question was inserted where participants could make suggestions for improving the system. Errors were recorded by this researcher and entered into the form with the knowledge and agreement from the participants. The data about these errors was already discussed in the initial part of this section. It happened because quantifying their occurrence and verifying error types were important in the discussion and argumentation about specific evaluations discussed throughout this section.

As for the improvement suggestions, a small part of the participants contributed with an answer (5; 16.7%). The suggestions were as follows: "Include games" (P03); "Have more places available at 'Window 1'" (P06); "Include tools for health monitoring" (P12, P18); and "Decrease the number of functions" (P19). Some of these suggestions, in a way, had also been registered in the think-aloud protocol, namely the suggestions expressed by participants P06, P12, and P19. Even if few, these suggestions are important when introducing improvements to the system, even though some should not be incorporated as they are outside the scope of the DWS.

In general, the suggestions sought to expand the DWS functions, emphasizing functionalities aimed at health monitoring. This point can either reflect a legitimate concern of this population cohort or because, occasionally, it is something this generation has got used to living within.[126] P12's comment, initially registered in the think-aloud protocol, came when the user tested the DWS functionality regarding the emergency call. The suggestion to include games may come from the fact that, as observed in the DTL survey, among those who claimed to use the internet, 68.5% did it as a source of entertainment, as shown in Chapter 3.

[126] Many of these participants, for instance, are already used to using the emergency device provided and monitored by SCML. A small prop that, when pressed, makes an emergency call.

Participant P19, who suggested that the number of functions should be reduced—due to the profile of responses provided throughout the post-test form—was a participant who did not feel very engaged, found the application relatively hard to use, and did not consider that the DWS could be useful in his day-to-day. Additionally, this participant expressed: "[I] *do not understand any of this technology stuff*" (recorded in the think-aloud protocol), a common expression among users who can be affected by technophobia (already mentioned).

The data presented generally showed a positive evaluation of the DWS. Most participants found the use of DWS effective, felt engaged with the tool, and considered the system relatively easy to use. These types of data, among others, are essential in evaluating the usability of a system, as stated by Barnum (2010). Additionally, data are also very relevant because they show that most participants considered that DWS could improve the quality of time spent at home, being useful in their daily routine, facilitating their internet use at home, and communicating with friends, family, and institutions. Such relevance comes from the fact that **the data from the post-test form presented in this chapter validate the research hypothesis that the relationship of digital information with domestic architectural spatiality can benefit the inhabitants, as exemplified by using the DWS.**

The information referring to a large part of participants considering that the DWS dynamic aspect would be significant to their domestic use reinforces the argument that architectural spatiality can be more incisively included in the relationship with digital information. This approach shows a promising research path covered herein and in other works. Thus, the DWS, within its limitations and potentialities, quested to configure a possible manifestation of the vision proposed by Teyssot (2005), stating that an urgent task of architecture is "conceive tools and instruments like a second sort of body, incorporated into and extending our corporal powers" (p. 81), as mentioned in Chapter 2.

Finally, upon completing the "User Evaluation of DWS" test, the digital window concept proposed at the first part of this research could be explored. Digital information gained architectural relevance and, potentially, proved to be an alternative to favor the inhabitant. In a way, the positive evaluations by participants authorize the continuity of this type of research. Conversely, the errors, criticisms, and suggestions observed in this evaluation stage point to improvements to be pursued in future developments. It is worth remembering that here the digital window concept is focused on specific aspects of a particular population portion and was evaluated by members of this group. However, this concept may gain new architectural interpretations and act over other inhabitants' demands, expanding its possibilities for investigation, development, and application.

5.3 Conclusion

This chapter introduced the “User Evaluation of DWS” test, including its assumptions and goals, the description of test development, its application steps, and participants. The methods used in data collection were discussed, and the results achieved were presented. Based on these data, it was possible to undertake analyses and discussions allowing to evaluate the DWS usability, validate the research hypothesis, and register opportunities for future developments.

In “5.2.1 Test Premises and Goals,” the main assumptions, dimensions, and objectives that shaped the test development were expressed. In this context, an evaluation with both formative and summative character was proposed. Furthermore, usability dimensions such as efficiency, effectiveness, engagement, error tolerance, and ease of use helped to structure the design of the “User Evaluation of DWS” test. Therefore, among the main goals of this research stage are the evaluation of the DWS usability, the verification of the assimilation regarding aspects of the digital window concept by participants, and the mapping of errors and suggestions for future evolutions of the system. Finally, it is relevant to highlight that this chapter aimed at validating the research hypothesis through this set of goals.

In “5.2.2 Test Description and Participants,” the three main test formulation steps were described. This subsection also presented the criteria and contexts considered to select the 30 participants. The relevance of SCML and, more specifically, the administration of CDCBL along this process was evidenced (either in its human aspect, structuring the selection of participants, or concerning the physical space, providing room for the test realization). Lastly, all five test stages were described, and some data from the participants were presented and discussed.

In “5.2.3 Data Collection Methods,” the three methodological resources used to collect data from the “User Evaluation of DWS” test were presented. The post-test form was the central resource to collect data about the participants’ experience using the DWS. This form was developed following recommendations by Barnum (2010), Brooke (1995), and Lund

(2001). Further, systematic observation (Marconi & Lakatos, 1985/2002) and the think-aloud protocol (Ericsson & Simon, 1993) also proved to be valuable methodological tools to record data of other natures that corroborated the DWS evaluation and validation.

In "5.2.4 Results and Discussions," the collected data fostered analyzes and discussions about the DWS. Regarding usability, the evaluations by participants, in general, allowed classifying the DWS as a system with effective and efficient use, with which the participants felt engaged and could use it with relative ease. The errors observed were recorded and made it possible to locate its weak points. The evaluations showed the participants' preferences in terms of functionalities and concerning the means of interaction. Through the form, it was still possible to measure the evaluation by participants about important points for validating the hypothesis, such as the fact that most participants considered the DWS as an element capable of improving the time spent at home, facilitating their access to the internet, or even consider the dynamic aspect of the apparatus relevant.

Therefore, it is possible to understand this evaluation phase as the endpoint of the research second part. It is important to note that this second part began with data and particular characteristics about issues related to population aging in Lisbon (Chapter 3). Subsequently, in Chapter 4, the development of the DWS apparatus was presented. This development is an alternative to the questions raised within the first part of the research (Chapter 1 and Chapter 2) in light of the data and contexts dealt with in the aforementioned Chapter 3. Ultimately, the data discussed in this chapter evidenced both the positive evaluation of the DWS as well as the validation of the research hypothesis.

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Conclusion

Conclusion

This final section of the research is constituted by a summarized presentation of the chapters developed, where it is possible to perceive the implementation of the methodological structure aligned with its secondary goals reached and the resulting contributions. As follow, hypothesis confirmation and the exposition of the main goal achieved are demonstrated. Finally, the research questions are answered, and paths for future improvements are pointed out.

a. Research Synthesis

The first chapter elaborated on a theoretical approach to domesticity, cybernetics, and artificial intelligence. The manner of structuring these topics sought both to present relatable dimensions among said subjects and to demonstrate points of tangency with architecture. In this way, it addresses issues arising from contemporary ways of living, population aging, and the concept of aging in place.

Throughout the first chapter, it sought to show that architecture can play an important role in facing particular demands growing within this context. At the same time, the research addressed the systemic bias of architecture from its relationship with cybernetics. Such bias favors the incorporation of AI tools as elements to ease the interaction process involving inhabitant, space, and digital information.

In the second chapter, the digital window concept was proposed, being one of the main contributions of this research. Said concept is supported by a theoretical structure that permeates the weakening of dualities perceived in contemporary times and its implications to some concepts. Research shows that the concepts of prosthesis and materiality have been expanded, their intrinsic dualities have become less antagonistic and more complementary (respectively: natural and artificial; materiality and immateriality).

Concomitant to these approaches, the digital window concept is also based on the virtual window metaphor proposed by Anne Friedberg (2006). Hence, the concept of digital window refers to a metaphorical architectural element—with certain qualities partially comparable to the conventional window—based on visualizing digital information using the constructed space as its support. In this second chapter, related works that illustrate or contextualize the digital window concept were also presented.

In the third chapter, a large data set, among those made available by official institutes and others raised by this research, contextualized aspects regarding population aging in Lisbon. Official data showed that approximately a quarter of the population in the municipality of Lisbon counts 65 years or more. Other official data indicate that practically three out of five older adults have access to the internet, a significant number, but which also show that two-fifths of this population cohort remain digitally excluded (in the DTL survey, approximately 50% of the sample had internet access, while the other half did not have).

Another significant contribution of the research is the data collected through the DTL survey, which shows that the larger piece of the sample spent most of their active time in the living room, television and cell phone being the electronic components they made use the greater part of the time. The survey also recorded that an overwhelming number of the sample did not intend to move to another house or go to a nursing home, reinforcing the pertinence of the aging in place concept. Finally, the research concerning the traditional habit of staying at the window (*janelar*) was investigated through unsystematic observation and data collected using the DTL survey. The data obtained helped to model part of the proposed developments in the Digital Window System.

The fourth chapter presents the main assumptions and objectives of the Digital Window System development. This system configures an important research outcome as it is a possible manifestation of the digital window concept, designed in the context of demands and characteristics of older adults mapped in Chapter 3. In this system, natural language processing and computer vision are branches of AI highlighted for having been adopted as alternative interaction tools. In certain scenarios, with the occurrence of possible physical limitations, such diversity of interaction means is an opportune strategy.

The elaboration of the DWS apparatus involved the development of its physical and abstract components, which it is reported in the final part of the fourth chapter (additionally, it can be analyzed in detail in the appendices gathered in Volume 2 of this thesis). Manufacturing the prototype employed from electronic components such as processing boards and stepper motors to wooden and plastic parts generated through digital fabrication. For elaborating the Digital Window App software, the *MIT App Inventor* platform was used to develop applications for mobile devices, such as the one used in the DWS apparatus.

The apparatus allows the inhabitant to dynamically control the position of the digital window projection on the internal surfaces that shape a particular domestic spatiality. The DWS was initially developed to be used in the living room. Such choice stems from the fact that most of the DTL survey sample had this space as their favorite and where they spent most of the time, as mentioned.

The system main functions take general inspiration from habits resulting from *janelar* and seek to facilitate digital inclusion. Therefore, its chief design strategies were to incorporate habits already consolidated in this segment of the population (such as watching television, for instance); also, to allow access to the internet and some of its functionalities (such as making video calls) in an environment that is occasionally more accessible and with visualization facilitated by the spatial approach of the system.

The fifth chapter assessed the system through the “User Evaluation of DWS” test. The test sought to evaluate the system usability, user preferences, and some questions regarding the digital window concept. The test consisted of the guided use of the DWS apparatus by 30 participants (older adults selected by SCML), with the application of a post-test form and other methodological tools concomitant with the test.

The test results were generally positive, showing that most participants felt engaged with the DWS and evaluated it as effective and efficient. As for ease of use, the evaluations were less positive, pointing out that the system could have an even more straightforward interface. The few recorded errors are related to the AI tools, which can also be improved. User preferences, in terms of features and means of interaction, were generally balanced, indicating that the diversity of options offered by the system was well assimilated.

b. Research Results and Contributions

It is significant the fact that most participants consider that using the system would improve the quality of time spent at home and that it would facilitate domestic use of the internet, as well as communication with friends, family, and institutions, are substantial. Such evaluations indicate that approaches of this nature can be relevant in the process of digital inclusion and, more than that, improve the inhabitant's domestic experience. The latter is a fundamental point for validating the research hypothesis. In this sense, the fact that an overwhelming number of participants considered the DWS dynamic aspect important for their domestic use collaborates to validate the hypothesis, once this finding reinforces the importance of the spatial dimension related to digital information to enhance the domestic experience, as proposed herein.

Therefore, through the results from the test presented in Chapter 5, the evaluation of the DWS allowed both mapping problems to be faced in future work and validating the research hypothesis. Accordingly, the manifestation of the proposed digital window systematically evidenced that relating domestic spatiality with digital information can allow the creation of new architectural systems beneficial to the inhabitants.

The work demonstrates that the main goal of developing an architectural system, based on the relationship between domestic spatiality and digital information, capable of enhancing the domestic experience of the inhabitant has been achieved. As seen through the synthesis of the five chapters of the thesis, one can note that the secondary goals were achieved as well.

Thus, it establishes a historical, theoretical, and critical framework of the main concepts related to domesticity, cybernetics, and AI (Chapter 1). The structuring digital window concept was proposed and works related to this concept were presented (Chapter 2). Data to contextualize the issue of population aging in Lisbon were collected, creating a development context for the Digital Window System (Chapter 3). A systemic approach to architecture was put forward, with the digital window concept as an assumption and the data collected in chapter 3 as the basis of the DWS proposal (Chapter 4). Finally, the secondary goal of testing and validating the DWS apparatus was also achieved (Chapter 5).

As for the research questions:

a) *Can the development of a human-centered architectural system based on the relationship between domestic spatiality and the visualization and manipulation of digital information benefit the inhabitant?* Both the analysis on the creation process of the system proposed and the evaluation data reported in Chapter 5 allow an affirmative answer to the question, which becomes even more evident when observing that a majority among participants considered that the DWS would improve the quality of time they spent at home.

b) *What would be the appropriate methodology to achieve the established goals? Could this methodology be useful for other studies of a similar nature?* The methodology, divided into five phases, proved to be effective since the goals were achieved. Furthermore, as the DWS is considered a possible manifestation of the digital window concept, this same methodological basis can lead to developing other manifestations/realizations of a similar nature.

c) *Are the theoretical structure and the proposed conceptual interweaving coherent with the developed system?* As much as other concepts and theories could have been addressed, the theoretical relationship that resulted in the digital window concept proved capable of theoretically structuring the DWS developments. Hence, it is possible to state that the theoretical structure is consistent with the developed system.

d) *Is the developed system able to support the inhabitant's specific demands (in this case, older adults)? What types of demands can be addressed?* The evaluation process results allow for a positive answer to this question. As an example, it is reasonable to affirm that the DWS can facilitate the process of digital inclusion and consequently provide a more active life (as defended by some authors discussed in Chapter 4). The system also improves the quality of time spent at home; increases the opportunity for entertainment; provides means to reduce social isolation; allows emergency calls to be made; provides alternative interaction means as a strategy to circumvent any physical limitations, among others. However, it is relevant to recognize that many other needs of older adults have yet to be addressed, and many of them are beyond the reach of architecture and the possibilities offered by the digital medium. Broadly, the results achieved allow one to believe that other demands arising from contemporary ways of living, in theory, can also be assisted by this type of development.

This research leaves as its main general contribution the understanding that a systemic approach to architecture is a significant path to be explored to address the challenges imposed by contemporaneity and the advances in information technology. In this context, the main contributions of this research are the established of digital window concept; the data rigorously collected exclusively by this research through an extensive survey (DTL); the observation and characterization of the *Janelar* phenomenon and its particularities in the Lisbon context; the developed system (DWS), as well as its development process; and, finally, the evaluation methodology. Furthermore, it is relevant to point out that both the digital window concept proposed, the collected data, and the method of development employed in this research can serve as a basis for other studies.

c. Future Works

The evaluations reported in Chapter 5 unfolded two main improvement paths (besides the few suggestions from the participants): making the system more straightforward; and quest for more inclusive and robust AI systems capable of avoiding the mistakes that happened in the test phase. As to simplifying the system, it is possible to develop a new version of the DWA with a more intuitive layout, aiming to simplify especially the "Window 2," responsible for video calls, identified as the most difficult one to be used by a considerable number of participants. Regarding AI systems, besides expanding the training database (especially concerning image recognition), an alternative to be analyzed is to pursue other support algorithms (especially for speech recognition).

The prototype also needs to undergo revisions, especially to improve the sensitivity calibration of the issuer control, since the testing stage showed that there is still room for improvement relating to its use linked to the body. Another issue regarding the issuer control is the size, which is larger than desirable. An alternative to be explored is to search for even more compact components and assemble a device to fit the body in a more intuitive, ergonomic, and comfortable way.

Once the theoretical structure present in this research is consolidated, as well as its development stages and results, it is necessary to promote its dissemination. With the themes and line of action better defined (compared to the publications reported in “g. Academic Developments”), taking part in related scientific events and specialized journals is required. Furthermore, scientific dissemination makes enables to find other researchers and research groups to help the continuity of this research. Accordingly, a final intention is to expand the goals that arise herein and explore new ways of conceiving architecture.

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