

Title: Living In Light

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Abstract:

This research investigates the integration of Human-Centric Lighting (HCL) in social residential apartment design. Using a daylight via studies methodology, we analyze lighting performance across different façade and interior configurations. Supporting this analysis are case studies of exemplary social housing projects, which provide contextual insights, and a comparative evaluation of design alternatives to refine strategies. The findings highlight innovative approaches to maximizing natural and artificial light integration for enhanced occupant well-being and sustainability.

Keywords: Human-centric lighting, natural light, Social housing, Indoor comfort , Residential buildings.

Table of context

- 1. Introduction..... 4
- 2. Background Context..... 6
 - 2.1 HCL Principles..... 6
 - 2.2 The Role of Daylighting in Social Housing 7
 - 2.3 Challenges in Urban Residential Design..... 8
- 3. Methodology 9
 - 3.1 Preliminary Research..... 10
 - 3.2 Case Study Analysis 12
 - 3.3 Daylight via studies methodology 14
 - Step 1: Define objective 14
 - Step 2: Building information model (BIM)..... 14
 - Step 4: Test and evaluation 16
 - 17
 - Step 5: Optimize design 20
 - 3.4 Comparative Analysis..... 21
 - 3.5 Synthesis and Application 22
- 4. Application to Design..... 24
 - 4.1 Proposed Design..... 24
 - 4.2 HCL Integration 25
- 5. Conclusion..... 25
- 6. Acknowledgements 26
- 7. References 27

1. Introduction

The intricate and dynamic relationship between the phenomena of light and the structural art of architecture has significantly influenced and shaped many design philosophies that have emerged and evolved throughout different historical periods. As the renowned architect le Corbusier profoundly articulated in his celebrated assertion, “Architecture is the masterly, correct, and magnificent play of masses brought together in light. Our eyes are made to see forms in light: light and shade reveal these forms.”, This statement not only underscores but illuminates the essential and transformative role that light plays in shaping and defining the multifaceted experiences of space within architecture contexts [1]

Natural light which is often considered simply as a matter of aesthetic preference in various architectural designs, should not be underestimated in its profound role a crucial and essential elements that significantly enhances human well-being: it provides countless advantages related to the regulation of circadian rhythms, positively influences emotional states by elevating mood, and serves to boost overall productivity levels in a variety of settings , as elucidated by the research conducted by Alkhatatbeh and Asadi in the year 2021 [2].

Nevertheless, contemporary urban housing frequently exhibits a tendency to compromise the availability of the daylight ingress, primarily as a result of their compact special configurations and the restricted exposure of their facades to natural light sources. This particular challenge becomes more evident in the realm of social housing developments, where fiscal limitations impose significant boundaries that further reduce the opportunity for innovative architectural designs that could otherwise improve daylight access [3].

The conventional architectural layout characteristics have elongated, poorly lit corridors along with the residential units that posses single façade orientation, both of which the entry of natural lamination, thereby resulting in suboptimal interior lighting conditions and an increased reliance on artificial lighting methods [4]

The progression and enhancement of techniques specifically designed to include natural daylight into architectural designs have been examined and articulated in recent academic research, with particular focus placed on the profound effects that such integration has on the overall comfort, satisfaction, and mental well-being of individuals living within these environments. The effect of exposure to natural daylight on psychological health is considerable, as it has been shown to considerably reduce the occurrence of headaches, alleviate eye strain, and lower stress levels, thereby highlighting the critical need of implementing effective daylighting systems within architectural frameworks to greatly improve the comfort and quality of life for the occupants (Tabadkani et al., 2021).[5], the application of dynamic lighting solutions within social housing environments has the potential to significantly improve the satisfaction levels .Furthermore, the integration of Human-Centric Lighting (HCL) principles has emerged as a common trend in contemporary architectural design methodologies, which aim to replicate the qualities of natural daylight and thus support the synchronization of circadian rhythms among residents [6].

The incorporation of HCL methodologies into architectural practices has been substantiated as a highly effective strategy that significantly improves the quality and functionality of both commercial and residential building projects, thereby contributing to their overall success and user satisfaction. This innovative strategy represents a considerable shift in lighting design, moving beyond traditional views of functionality and aesthetic appeal to a holistic understanding of the physiological and psychological impacts that light can have on individuals, thereby transforming our approach to lighting in built environments. [7] HCL systems possess the ability to be precisely programmed according to specific schedules, incorporating both occupancy-based and individualized control mechanisms This facilitates the development of advanced and intelligent lighting environments that substantially reduce energy consumption while preserving light quality, user comfort, and essential safety standards. This innovative method effectively sustains the desired levels of illumination throughout the whole day, thus using a direct and beneficial influence on the well-being of the residents who live in these spaces. [8]

2. Background Context

2.1 HCL Principles

HCL has fundamentally changed the methodologies and conceptual frameworks that architects employ in the realm of lighting design, placing a strong emphasis on the intricate dynamics of biological rhythms and the psychological comfort of individuals inhabiting the spaces they create. In contrast to traditional lighting solutions that often neglect the relationship between many parameters of illumination, HCL recognizes and addresses the complex exchange between light intensity, color temperature, and the naturally occurring circadian rhythms that control human physiology and behavior. Numerous research studies have demonstrated that exposure to blue-rich light in the early morning hours can significantly enhance levels of alertness and productivity, whereas the introduction of warmer color hues during the evening hours has been shown to ease relaxation processes and contribute to improved sleep quality for individuals [2].

Furthermore, HCL aligns with the foundational principles of sustainable architectural practices, as it effectively reduces dependency on energy-consuming artificial lighting systems by optimizing ways that maximize the use of natural daylighting within built environments. The successful integration of HCL into the design of residential spaces demands an understanding of the non-visual effects of light, which include aspects such as circadian stimulation and the enhancement of emotional well-being, ensuring that these critical factors are realized through thoughtful architectural elements including the placement of the building, the implementation of shading devices to regulate light entry, positioning of openings and the careful assessment of interior reflectivity to enhance overall lighting quality and experience [3].

2.2 The Role of Daylighting in Social Housing

Daylighting, which refers to the deliberate and strategic integration of natural sunlight into the design of buildings, has increasingly been recognized as an indispensable and vital element in the architectural planning of social housing developments. The benefits associated with the effective use of daylight extend far beyond simple energy conservation; they include a wide array of benefits [4][3]. Research has demonstrated that environments that are well-illuminated by natural light have the ability to reduce stress levels significantly, improve mental clarity and cognitive function, and foster a profound sense of openness and spaciousness, particularly within populated residential areas where such qualities are often absent.

Factual case studies, such as the notable Leyton House located in London [9], illustrate the effective implementation and integration of daylighting strategies within residential architecture. This project thoughtfully utilizes central courtyards and expansive open areas specifically designed to optimize the entry of natural light into the building's interiors, significantly reducing dependence on artificial lighting during daylight hours. Similarly, the use of light-reflective materials, along with the incorporation of reflective surfaces, further enhances the influx of natural light in densely populated urban settings, thus improving living standards and enhancing the overall quality of life for residents.[4]

2.3 Challenges in Urban Residential Design

Urban density poses a multitude of challenges that significantly impede access to natural daylight within residential environments. In the typical social housing designs, it is often observed that layouts are characterized by single-sided apartments, which inherently limit only a restricted degree of exposure to the beneficial effects of natural light. Consequently, these architectural designs culminate in the creation of dimly lit corridors, inadequate air circulation, and an excessive reliance on artificial lighting sources to compensate for the deficiencies in natural illumination. Therefore, it is essential to strategically position architectural elements that promote daylight optimization, such as ventilation gaps and dual façades, to effectively address and mitigate these widespread issues [3].

Furthermore, in urban environments, various contextual constraints often emerge, such as the limitations due to compact building footprints, strict zoning regulations, and the demands of economic viability. Considering these complex factors, architects are forced to navigate a complex landscape where they must delicately balance these many considerations while simultaneously seeking to achieve optimal levels of daylight access and adequate ventilation. This underscores the critical importance of pursuing design solutions that can effectively settle these competing needs within the context of urban living [3][2].

3. Methodology

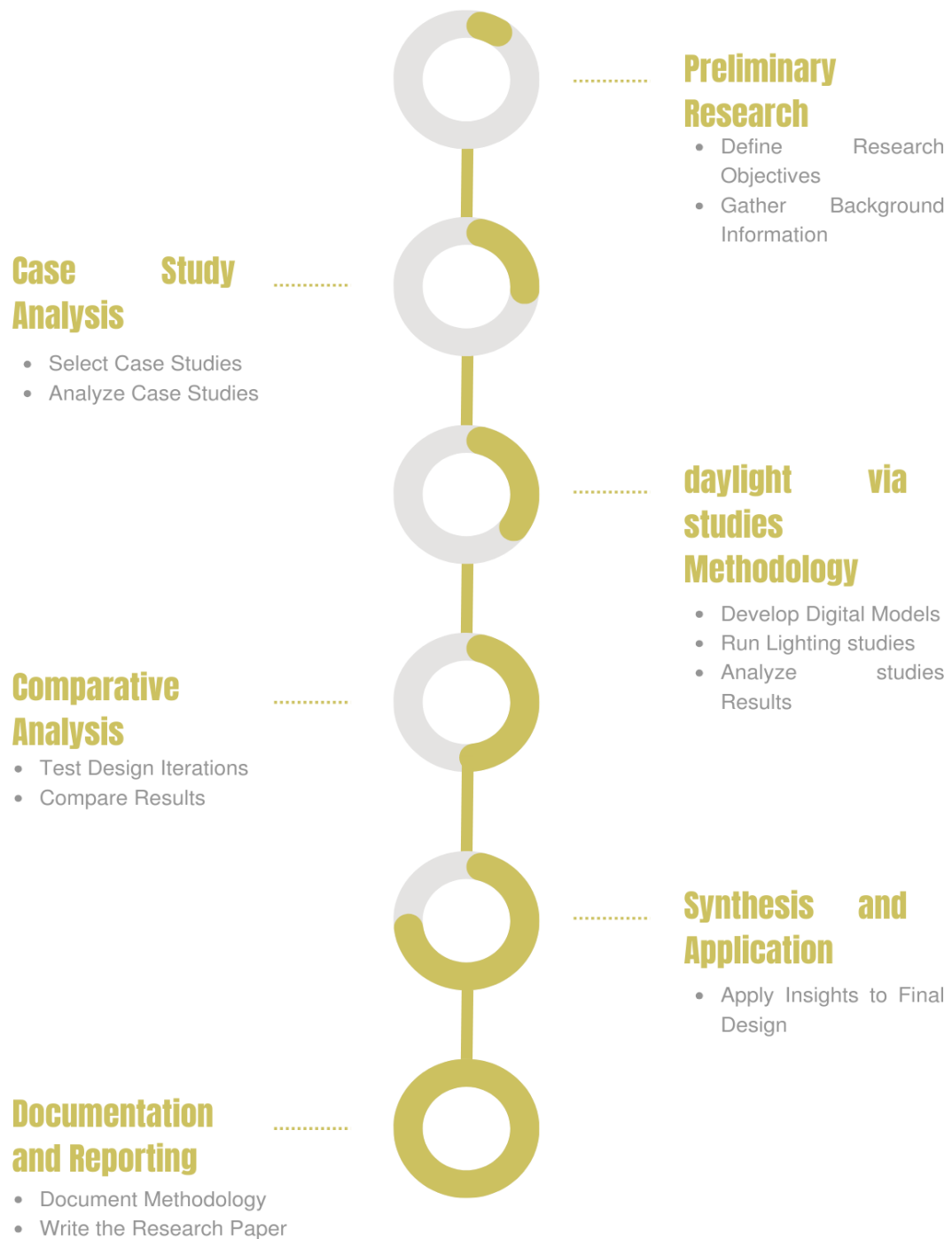


Figure 1: methodology steps (author's work)

3.1 Preliminary Research



Figure 2: arial view of the project site taken from google earth

The semester project involved the design of a comprehensive 65-unit social housing building, which was required to adhere with a set of specific criteria that encompassed various important components, including but not limited to minimum room area dimensions, the deliberate integration of social and multi-functional spaces, storage facilities, parking areas and more. The foremost challenge faced during this undertaking resided in the balancing act of harmonizing these functional imperatives with the critical necessity to offer a quality of living to each resident, which led the inquiry: “How can we guarantee an elevated quality of life for the inhabitants while reducing dependency on energy-intensive systems, which include artificial lighting and ventilation?”

The research effort was primarily directed towards addressing this multifaceted challenge by examining the foundational key metrics of Human-Centric Lighting (HCL) and exploring the pivotal metrics that are associated with the use of natural daylight. A thorough and comprehensive review of the existing body of literature provided a robust foundation for this inquiry, which in flipped offered insights into the interplay between the availability of natural light, the details of spatial design, and the broader array of challenges that are currently facing contemporary urban housing developments. This review illuminated the fact that HCL systems, which are designed to prioritize not only the visual needs of individuals but also their non-visual physiological and psychological

requirements, have the potential to significantly enhance the overall quality and livability of residential environments, as supported by the findings of Di Nicolantonio et al. (2020) [4]. Furthermore, the comprehensive and extensive literature review has emphatically emphasized the critical and paramount significance of various specific metrics associated with daylighting, which notably include, though are not exhaustively limited to, the Daylight Factor (DF) and Circadian Stimulus (CS), in the meticulous and rigorous evaluation and assessment of lighting performance within the context of residential environments, a salient point that has been thoroughly highlighted and corroborated by the research findings and analyses conducted by Lee and Boubekri in the year 2022.[10]

3.2 Case Study Analysis

the "72 Social Housing Units at the Marina del Prat Vermell" was a huge help in understanding that prioritizing the quality of living by light exposure is possible even for social houses, it has yielded a wealth of practical insights into the complex and nuanced integration of natural light within contemporary residential environments, thereby contributing significantly to the discourse on sustainable architectural practices. The architectural design of this particular housing complex, which is strategically located within the historical neighborhood of Marina del Prat Vermell, employs a distinctive and innovative layout that has been carefully adapted to fit the unique triangular plot of the site, showcasing a profound understanding of site-specific design principles. The building itself is astutely organized into five distinct volumes, which are effectively separated by two north-south-oriented courtyards and passages, a design choice that not only enhances the aesthetic appeal but also significantly optimizes the flow of natural light and ventilation throughout the various residential units, thereby improving the overall living experience for the inhabitants.



*Figure 3: Showing the openings and red façade material
picture taken from ArchDaily by Adrià Goula*

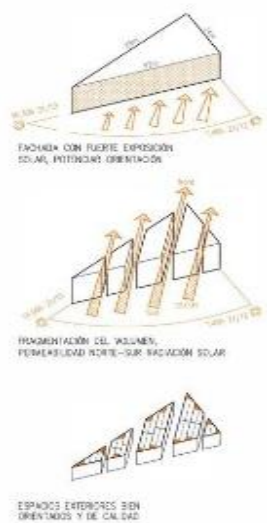


Figure 4: diagram taken from archidaily by:mias arch

The architectural strategy incorporates clear vertical strips of glass, all over the facades which illustrates how the integration of dynamic glazing systems can markedly improve the incorporation of natural daylight into various residential architectural projects, which in turn serves to corroborate and reinforce the previously established findings that are related to the optimization of lighting conditions within indoor environments, as highlighted in the aforementioned study (Liu and Wu, 2022).[18], when combined with the striking red-colored fiber-reinforced concrete facades, serves to not only elevate the visual engagement of the design but also to evoke a deeper historical connection to the site's legacy of fabric dyeing, thus enriching the narrative of the building's architectural identity.

This integration of natural light is further augmented by the implementation of sustainable design strategies, which include the use of lightweight prefabricated materials and the installation of a shared photovoltaic plant on the roof, a significant feature that produces renewable energy and effectively meets a substantial portion of the building's energy requirements. Collectively, these carefully considered features exemplify the efficacy of innovative architectural responses to the multifaceted challenges that are typically presented by densely populated urban environments, imparting invaluable lessons that are highly applicable to the evolving field of residential architecture and its future development [9]

3.3 Daylight via studies methodology

The implementation of a 5-step strategy into the study to help organize the ideas and structure the correct foundation for the results:

Step 1: Define objective

In this case the main question was the core of the research objective “how can we insure a good quality of living for the inhabitant without asking for more energy consuming costs such as artificial lighting systems, ventilation systems, air conditioners and etc...?” this was followed by this question “how can we optimize the building design for daylighting efficiency?”

Step 2: Building information model (BIM)

To initiate the process of implementing empirical readings and conducting studies, a three-dimensional Building Information Modeling (BIM) model of the building was constructed. Drawing upon the author’s previous engagement in a research paper that extensively discussed the BIM, it was ascertained that the most efficient and precise methodology would involve the creation of a detailed three-dimensional model for each individual module within the structure. A substantial emphasis was placed on fundamental elements such as the strategic positioning of fenestration, the orientation of the edifice concerning solar angles, the characteristics of materials that influence the behavior of light within the interior, as well as the imperative necessity to ensure that all dimensions and spatial configurations were exact and representative of actual measurements. The selection of ArchiCAD software for this purpose was predicated upon its capacity to produce a model that is both comprehensive and exceptionally detailed. This developed model subsequently functioned as the cornerstone for the execution of the study, facilitating ongoing improvements that were informed by the diverse design decisions made throughout the entire process.

Step 3: Analyze daylight

The highly detailed Building Information Model (BIM) that was developed during the second phase of the project was integrated into an advanced daylight visualization application created by (VELUX). This integration facilitated a thorough analysis of how natural light interacts with various components of the structure. This thorough analysis took into account a multitude of critical factors, including but not limited to, the precise geographical location of the site in relation to its surroundings, the specific orientation of the building in accordance with cardinal directions, and the exact dimensions of the structure, thereby ensuring a holistic and comprehensive understanding of the complex dynamics of daylight as they pertain to the overall architectural design.

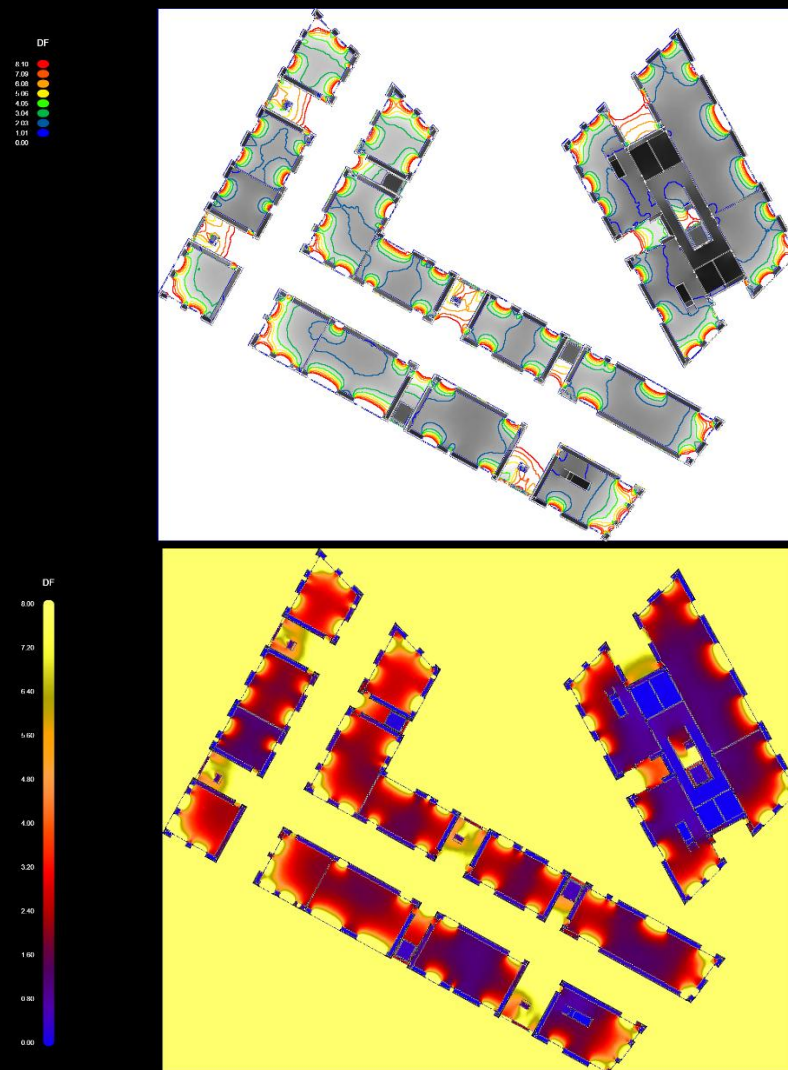
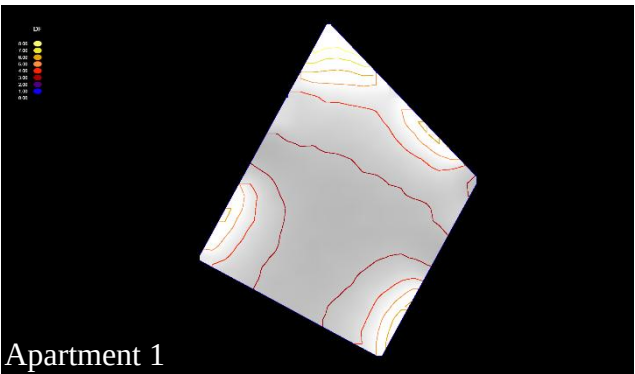


Figure 5: figure showing the general DF for the whole floor plan made by velux (authors work)

Step 4: Test and evaluation

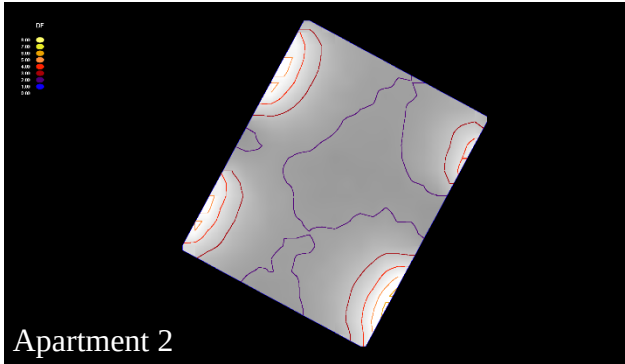
Measuring the daylight penetration on each apartment area zone in one of the floors and the overall brightness levels of the interior and some exterior spaces, an evaluation was taken and compared to the **EN17037** for Hungary which is:

EN17037 for Hungary the target daylight factors (D_T) are 1.7% (300 lux), 2.8% (500 lux) and 4.1% (750 lux). The minimum daylight factor target (D_{TM}) is 0.6% (100 lux). [11]



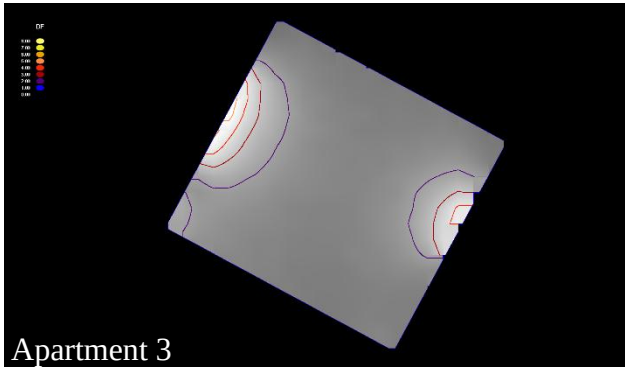
Average	D	3.59%
Median	D	3.13%
Minimum	D	2.60%
Maximum	D	9.42%
Uniformity 1	D_{min}/D_{avg}	0.7246
Uniformity 2	D_{min}/D_{max}	0.2762

EN17037			
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass (>95%)
$F_{plane, \%} \geq 1.7\%$	D_T	100%	Pass (>50%)
$F_{plane, \%} \geq 2.8\%$	D_T	76%	Pass (>50%)
$F_{plane, \%} \geq 4.1\%$	D_T	22%	Fail (<50%)



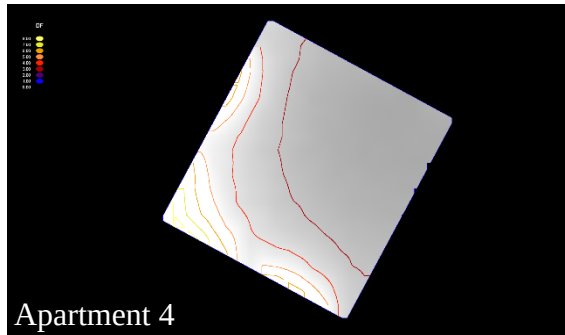
Average	D	2.50%
Median	D	2.14%
Minimum	D	1.81%
Maximum	D	6.32%
Uniformity 1	D_{min}/D_{avg}	0.7239
Uniformity 2	D_{min}/D_{max}	0.2858

EN17037			
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass (>95%)
$F_{plane, \%} \geq 1.7\%$	D_T	100%	Pass (>50%)
$F_{plane, \%} \geq 2.8\%$	D_T	23%	Fail (<50%)
$F_{plane, \%} \geq 4.1\%$	D_T	6%	Fail (<50%)



Average	D	1.69%
Median	D	1.44%
Minimum	D	1.02%
Maximum	D	5.38%
Uniformity 1	D_{min}/D_{avg}	0.6046
Uniformity 2	D_{min}/D_{max}	0.1903

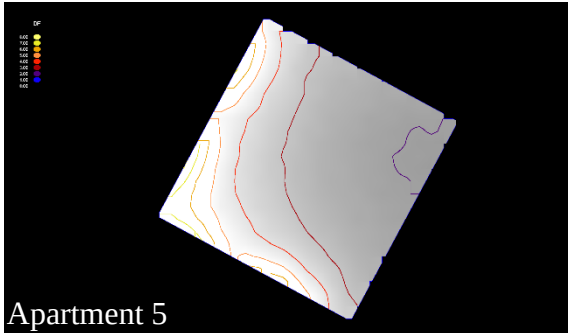
EN17037			
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass (>95%)
$F_{plane, \%} \geq 1.7\%$	D_T	29%	Fail (<50%)
$F_{plane, \%} \geq 2.8\%$	D_T	7%	Fail (<50%)
$F_{plane, \%} \geq 4.1\%$	D_T	2%	Fail (<50%)



Average	D	3.46%
Median	D	3.04%
Minimum	D	2.21%
Maximum	D	8.73%
Uniformity 1	D_{min}/D_{avg}	0.6405
Uniformity 2	D_{min}/D_{max}	0.2536

EN17037

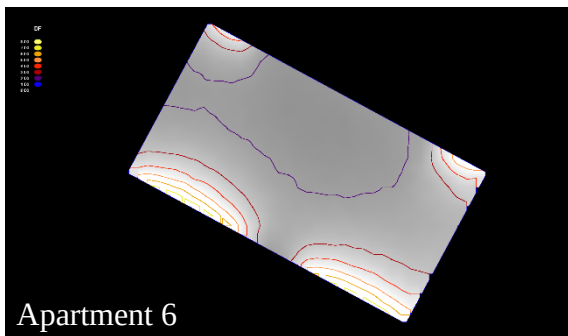
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	100%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	60%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	23%	Fail ($< 50\%$)



Average	D	3.46%
Median	D	3.06%
Minimum	D	1.92%
Maximum	D	7.98%
Uniformity 1	D_{min}/D_{avg}	0.5563
Uniformity 2	D_{min}/D_{max}	0.2410

EN17037

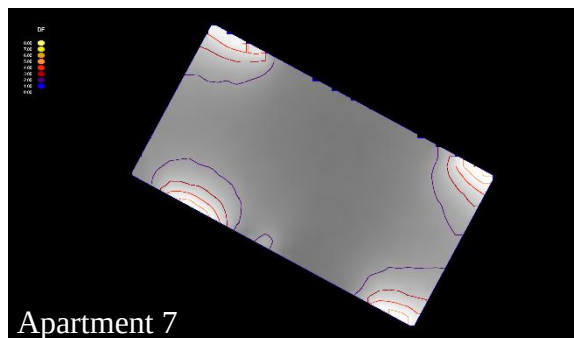
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	100%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	57%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	26%	Fail ($< 50\%$)



Average	D	2.67%
Median	D	2.26%
Minimum	D	1.66%
Maximum	D	7.73%
Uniformity 1	D_{min}/D_{avg}	0.6218
Uniformity 2	D_{min}/D_{max}	0.2152

EN17037

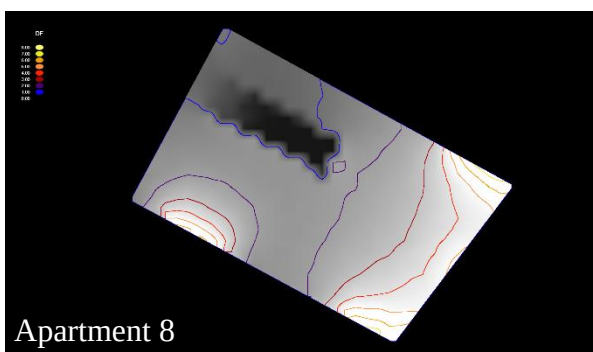
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	97%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	27%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	11%	Fail ($< 50\%$)



Average	D	1.82%
Median	D	1.56%
Minimum	D	1.13%
Maximum	D	6.14%
Uniformity 1	D_{min}/D_{avg}	0.6192
Uniformity 2	D_{min}/D_{max}	0.1837

EN17037

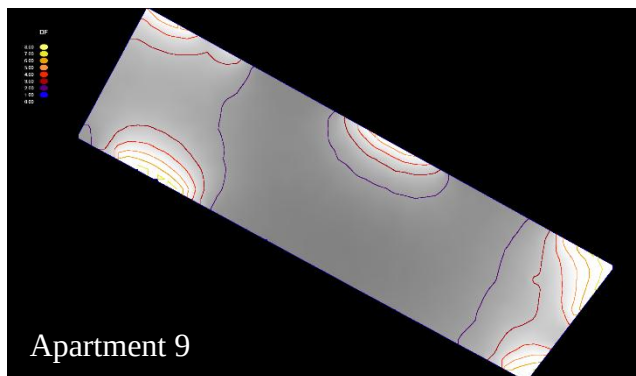
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	40%	Fail ($< 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	11%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	4%	Fail ($< 50\%$)



Average	D	2.34%
Median	D	1.96%
Minimum	D	0.03%
Maximum	D	7.88%
Uniformity 1	D_{min}/D_{avg}	0.0139
Uniformity 2	D_{min}/D_{max}	0.0041

EN17037

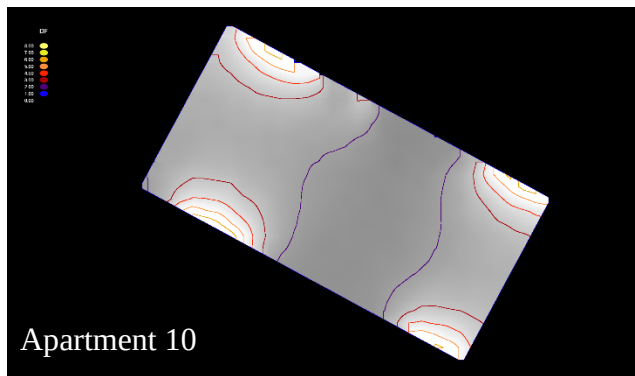
$F_{plane, \%} \geq 0.6\%$	D_{TM}	92%	Fail ($< 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	67%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	29%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	14%	Fail ($< 50\%$)



Average	D	2.38%
Median	D	1.96%
Minimum	D	1.28%
Maximum	D	7.49%
Uniformity 1	$D_{\min}/D_{\text{avg}}$	0.5389
Uniformity 2	$D_{\min}/D_{\max}$	0.1715

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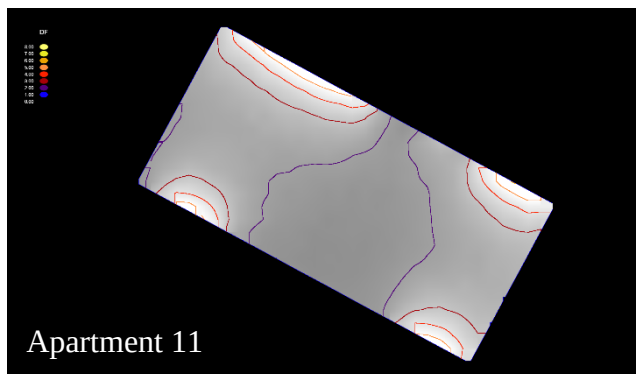
$F_{\text{plane},\%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{\text{plane},\%} \geq 1.7\%$	D_{T}	63%	Pass ($\geq 50\%$)
$F_{\text{plane},\%} \geq 2.8\%$	D_{T}	24%	Fail ($< 50\%$)
$F_{\text{plane},\%} \geq 4.1\%$	D_{T}	9%	Fail ($< 50\%$)



Average	D	2.56%
Median	D	2.32%
Minimum	D	1.54%
Maximum	D	7.09%
Uniformity 1	$D_{\min}/D_{\text{avg}}$	0.6016
Uniformity 2	$D_{\min}/D_{\max}$	0.2174

EN17037

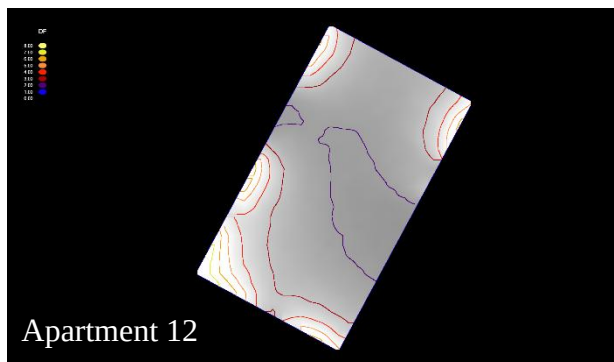
$F_{\text{plane},\%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{\text{plane},\%} \geq 1.7\%$	D_{T}	85%	Pass ($\geq 50\%$)
$F_{\text{plane},\%} \geq 2.8\%$	D_{T}	26%	Fail ($< 50\%$)
$F_{\text{plane},\%} \geq 4.1\%$	D_{T}	9%	Fail ($< 50\%$)



Average	D	2.52%
Median	D	2.25%
Minimum	D	1.59%
Maximum	D	6.29%
Uniformity 1	$D_{\min}/D_{\text{avg}}$	0.6319
Uniformity 2	$D_{\min}/D_{\max}$	0.2530

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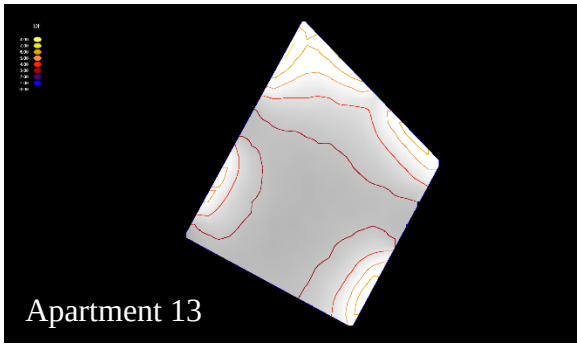
$F_{\text{plane},\%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{\text{plane},\%} \geq 1.7\%$	D_{T}	91%	Pass ($\geq 50\%$)
$F_{\text{plane},\%} \geq 2.8\%$	D_{T}	24%	Fail ($< 50\%$)
$F_{\text{plane},\%} \geq 4.1\%$	D_{T}	8%	Fail ($< 50\%$)



Average	D	2.85%
Median	D	2.41%
Minimum	D	1.76%
Maximum	D	8.03%
Uniformity 1	$D_{\min}/D_{\text{avg}}$	0.6172
Uniformity 2	$D_{\min}/D_{\max}$	0.2187

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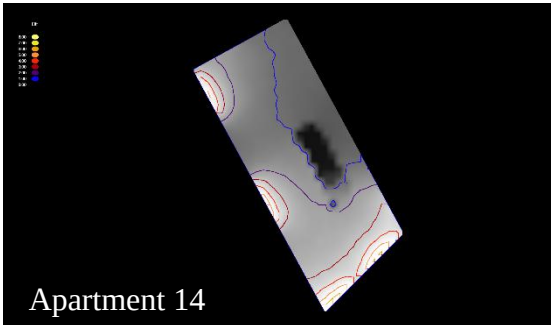
$F_{\text{plane},\%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{\text{plane},\%} \geq 1.7\%$	D_{T}	100%	Pass ($\geq 50\%$)
$F_{\text{plane},\%} \geq 2.8\%$	D_{T}	35%	Fail ($< 50\%$)
$F_{\text{plane},\%} \geq 4.1\%$	D_{T}	14%	Fail ($< 50\%$)



Average	D	3.60%
Median	D	3.15%
Minimum	D	2.31%
Maximum	D	7.39%
Uniformity 1	D_{min}/D_{avg}	0.6433
Uniformity 2	D_{min}/D_{max}	0.3131

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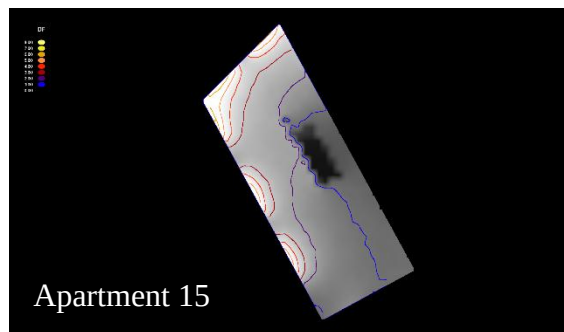
$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	100%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	77%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	24%	Fail ($< 50\%$)



Average	D	1.85%
Median	D	1.57%
Minimum	D	0.02%
Maximum	D	6.00%
Uniformity 1	D_{min}/D_{avg}	0.0116
Uniformity 2	D_{min}/D_{max}	0.0036

EN17037

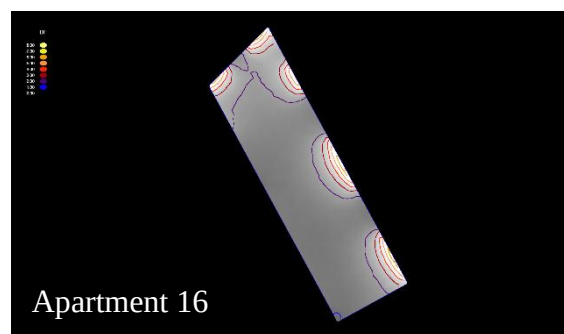
$F_{plane, \%} \geq 0.6\%$	D_{TM}	93%	Fail ($< 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	48%	Fail ($< 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	19%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	5%	Fail ($< 50\%$)



Average	D	2.05%
Median	D	1.84%
Minimum	D	0.02%
Maximum	D	6.92%
Uniformity 1	D_{min}/D_{avg}	0.0110
Uniformity 2	D_{min}/D_{max}	0.0033

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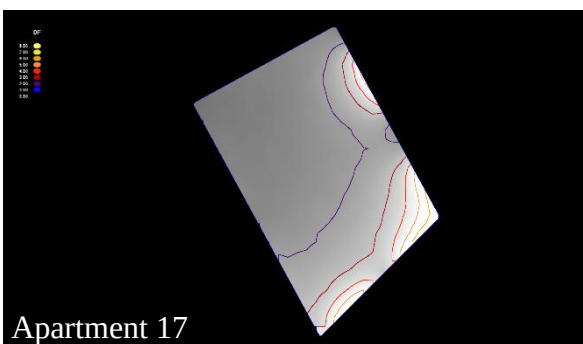
$F_{plane, \%} \geq 0.6\%$	D_{TM}	93%	Fail ($< 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	53%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	23%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	9%	Fail ($< 50\%$)



Average	D	1.91%
Median	D	1.52%
Minimum	D	0.96%
Maximum	D	6.85%
Uniformity 1	D_{min}/D_{avg}	0.5011
Uniformity 2	D_{min}/D_{max}	0.1395

EN17037

$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	41%	Fail ($< 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	14%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	5%	Fail ($< 50\%$)



Average	D	2.28%
Median	D	1.91%
Minimum	D	0.99%
Maximum	D	6.88%
Uniformity 1	D_{min}/D_{avg}	0.4353
Uniformity 2	D_{min}/D_{max}	0.1441

EN17037

$F_{plane, \%} \geq 0.6\%$	D_{TM}	100%	Pass ($\geq 95\%$)
$F_{plane, \%} \geq 1.7\%$	D_T	61%	Pass ($\geq 50\%$)
$F_{plane, \%} \geq 2.8\%$	D_T	23%	Fail ($< 50\%$)
$F_{plane, \%} \geq 4.1\%$	D_T	8%	Fail ($< 50\%$)

Step 5: Optimize design

Based on the results and observations, refining with some edits for the window sizes, position, layout, split was made, this process was done more than once until we reached satisfactory, specifically how it influences the whole space to change not only in light but functions. The comprehensive research conducted by Piraei, Matusiak, and Lo Verso in the year 2022 meticulously investigates the multifaceted challenges associated with the attainment of sufficient daylighting within heritage structures characterized by extensive spatial layouts and diminutive window openings, particularly emphasizing the conditions prevalent in urban environments situated at high latitudes. The findings of their rigorous study illuminate the fact that a considerable number of interior spaces contained within these historically significant buildings do not satisfy the established 2% Daylight Factor benchmark, thereby accentuating the substantial impediments presented by facades that are oriented solely towards one side in densely populated urban settings. [12] but in the results the average Daylight Factor benchmark for our building design for all 17 apartments per floor is 2.6%

3.4 Comparative Analysis.

In Figure 6, the preliminary design phase is illustrated, wherein generalized and mass-manufactured schematics were executed. This methodology engendered several obstacles, including the emergence of poorly illuminated zones within residential units, elongated and dim corridors, as well as apartments presenting only one or, at most, two facades, thereby neglecting the significance of the north-facing orientation. Conversely, Figure 7 exemplifies an enhanced design methodology, illustrating how the incorporation of solar penetration and natural cross-ventilation has been adeptly integrated into the architectural framework, thereby augmenting the overall quality of living environments.

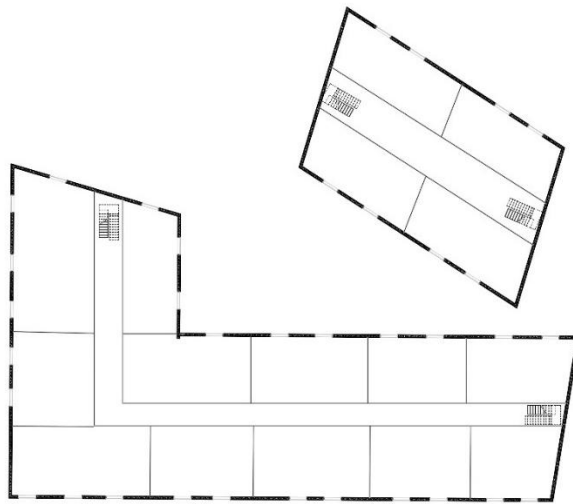


Figure 6: old floor plan layout made in archicad (authors work)

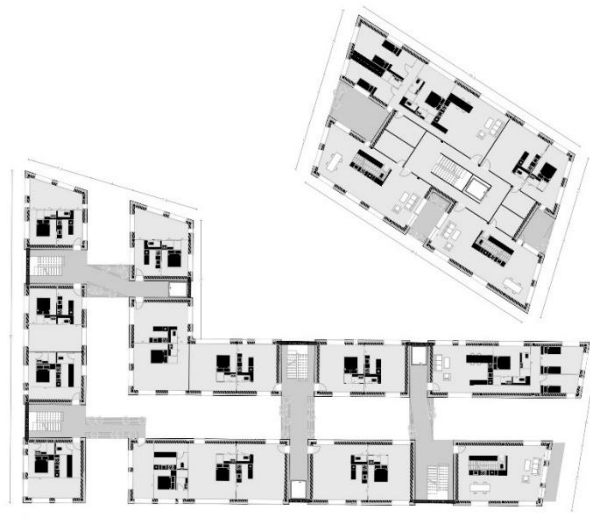


Figure 7: new floor plan layout made in archicad (authors work)

3.5 Synthesis and Application

The outcomes derived from this extensive and methodologically rigorous investigation were amalgamated and synthesized in order to refine, optimize, and elevate a prototype design for residential spaces that seamlessly incorporates and effectively embodies the foundational principles of HCL, thereby fostering an environment that prioritizes the well-being of its occupants. In the final configurations of the residential layouts, there was a strategic and purposeful emphasis placed on ensuring dual-sided exposure to the abundant and beneficial natural light, the inclusion of ventilation apertures strategically designed to enhance the circulation of air throughout the living spaces, and a conscientious effort to minimize the dependence on artificial lighting sources, which are often overutilized. Collectively, these thoughtfully implemented design measures culminated in a marked improvement in the comfort levels experienced by the occupants, as well as a substantial reduction in the energy expenditures associated with residential environments, a phenomenon that has been notably underscored by the research of Polyák (2016). [13].

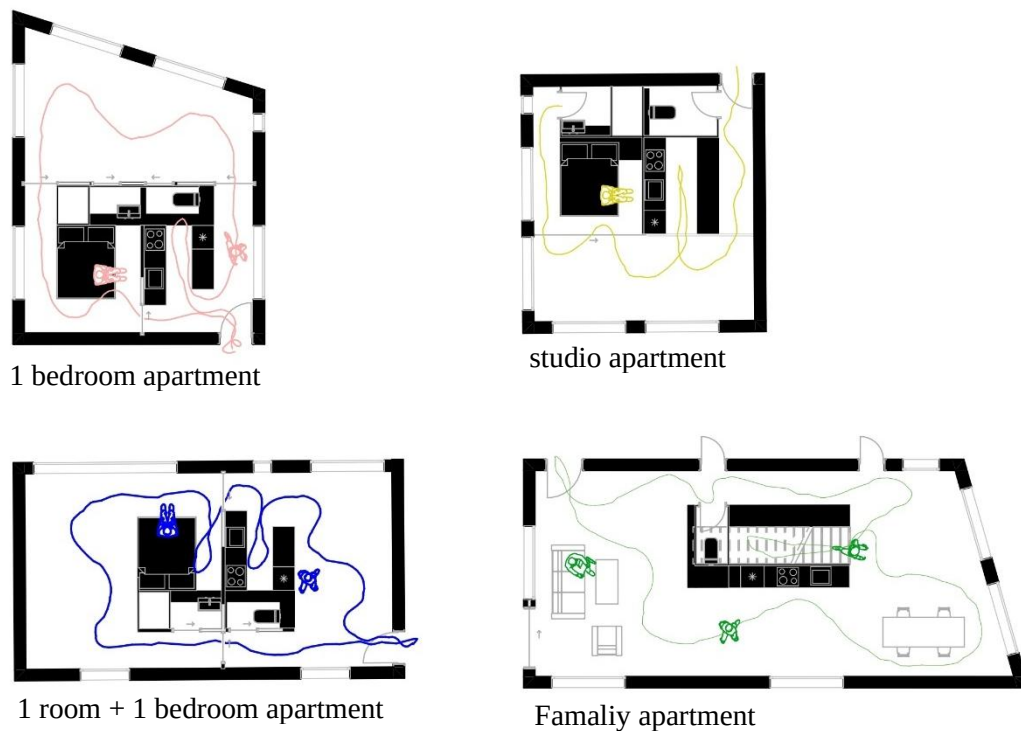


Figure 8: The four different layouts designed according to the criteria outlined in the project rules, illustrating the flow of human movement within the HCL-inspired apartments, created in ArchiCAD (author's work)

Furthermore, it is of paramount importance to underscore the fact that Montjoy (2024) has made a particularly noteworthy and salient observation, which posits that the meticulous and thoughtful integration of natural lighting, particularly when it is harmoniously combined with an array of various functional design elements, serves to cultivate and generate atmospheres that are not only conducive to a heightened sense of comfort but also visually stimulating, engaging, and intellectually invigorating to the occupants. This innovative and holistic approach aligns seamlessly and coherently with the overarching goals and objectives that guide the formulation and development of the final residential design concepts that have been meticulously articulated.[14]

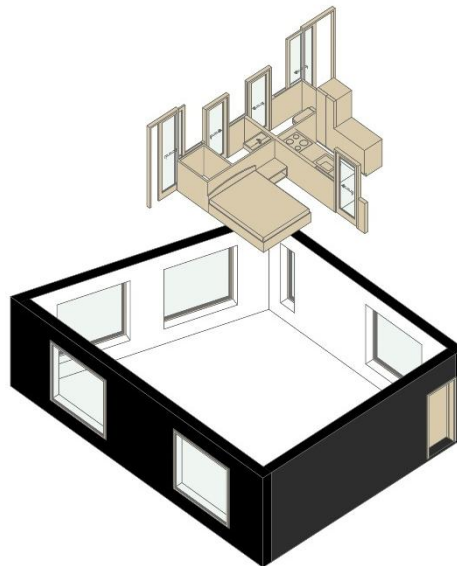


Figure 9: The two-layer construction concept for each apartment, showcasing the inbuilt oak core interior and the white reflective interior wall shell, covered with black fiber cement finish cladding, created in ArchiCAD (author's work).

4. Application to Design

4.1 Proposed Design

Among the various iterations of architectural design that have been explored and analyzed, those that strategically incorporate the innovative concepts of dual facades in conjunction with light wells have consistently demonstrated a marked superiority over traditional layouts, particularly in their ability to achieve not only enhanced light distribution but also improved ventilation throughout the built environment. Furthermore, these advanced design solutions have been shown to be aligned with the established criteria set forth by HCL for promoting circadian benefits, leading to a notable and quantifiable enhancement in visual comfort ratings, with reported improvements reaching as high as 25% according to the comprehensive study conducted by Kwon et al. in 2021 [7]. In addition to these advantages, the implementation of multi-skin facades has proven to be an effective strategy in mitigating glare, while simultaneously maximizing the availability of natural light within interior spaces, as highlighted by Phillips in his 2021 research [15].

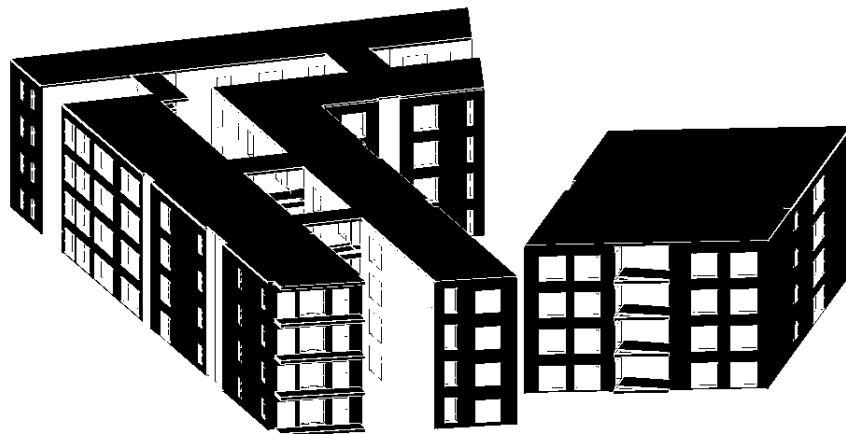


Figure10: Axonometric view of the overall look of the building inspired by HCL, created in ArchiCAD (author's work).

4.2 HCL Integration

Dynamic lighting systems, when utilized in conjunction with carefully designed natural daylight strategies, play a crucial role in facilitating the regulation of circadian rhythms, which are essential for maintaining a healthy sleep-wake cycle and overall well-being in individuals. Furthermore, the implementation of hybrid shading solutions not only guarantees the provision of thermal comfort within the built environment but also ensures that the quality of light is not compromised, thereby allowing for a meticulously controlled blend of both natural and artificial lighting sources to coexist harmoniously (Edensor, 2015) [8]

5. Conclusion

This comprehensive study serves to reinforce the undeniably pivotal and central role that natural light plays in the field of residential architecture, with a particular focus on its implications within the context of social housing, which is a vital area of urban development.

By incorporating Human-Centric Lighting (HCL) principles, a variety of innovative design solutions are introduced, including enhanced ventilation systems and carefully designed light gaps, which significantly transform and uplift urban living standards. This approach not only improves sustainability efforts but also promotes the general well-being of the occupants residing in these meticulously crafted environments.

Key highlights include advocating for dual-facade designs specifically aimed at maximizing access to natural light and air within living spaces, thereby cultivating an environment that optimally utilizes natural resources. Furthermore, the strategic application of advanced digital technologies is crucial for conducting accurate lighting simulations and ensuring comprehensive design validation processes that secure the best

possible lighting conditions. Additionally, there is an urgent need for comprehensive policy frameworks that incentivize the development of housing projects focused on maximizing daylight access, which would foster a lifestyle beneficial to enhanced quality of life for residents.

Future research initiatives should focus on exploring adaptive technologies that can effortlessly blend natural and artificial lighting systems to further enhance the application of HCL in residential contexts, ultimately resulting in more innovative and effective living spaces tailored to the needs of contemporary inhabitants.

6.Acknowledgements

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