Towards a new affordable housing approach: A system-thinking set of criteria to assess *quality*

by

David B. Gottdiener Islas

B.Sc. Industrial Engineering, Universidad Panamericana (2017)

Submitted to the System Design and Management Program
in partial fulfillment of the requirements for the degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology

May 2024

Authored by: David B. Gottdiener
MIT System Design and Management Program
February 22, 2024

Certified by: Christoph Reinhart, PhD
Professor; Director, Building Technology Program
Thesis Supervisor

Accepted by: Joan Rubin
Executive Director
MIT System Design and Management Program

Towards a new affordable housing approach: A system-thinking set of criteria to assess *quality*

by

David B. Gottdiener Islas

Submitted to the MIT System Design and Management Program

on February 22, 2024, in partial fulfilment of the requirements for the degree of

Master of Science in Engineering and Management

Abstract

Considering that the built environment footprint is expected to double by the second half of this century[1], mainly driven by growth – both economic and demographic – in developing countries, reconciling several tensions related to this expansion is of paramount importance.

Certainly, accommodating growth without sacrificing sustainability – considering prevalent manufacturing processes that enable the construction sector yield a substantial portion of global GHG emissions – and providing affordable housing without neglecting *quality*.

Thus, a deceivably simple question arises: what *is* affordable *quality* housing? Evidently, the question contains an opportunity – arguably, also an obligation – to employ a system-thinking perspective that observes – and is guided by – the relationships between housing and its broader urban system. So far, pervasive affordable housing development models (typically categorizing inert metrics as economic, social, and sustainable) have proven insufficient in several developing countries for their disregard to a system-thinking approach[2].

The goal of this work is to build a system-thinking approach that will enable a two-way dialogue between further research that better equip housing development stakeholders with the necessary set of criteria to think and act having in mind the expected *functions* that housing shall provide – enabling performance comparisons between multiple design concepts until desirable results are achieved by iterative improvements – and the empirical observations that reflect the dynamic nature of both housing needs and the methods to analyze and fulfill them.

Thesis Supervisor: Christoph Reinhart, PhD.
Title: Professor; Director, Building Technology Program

Thesis Supervisor: Joan Rubin, MSc.
Title: Executive Director and Senior Lecturer, System Design and Management Program

[1] See the Architecture 2030 article, citing the IEA and Statista as original data sources.
[2] See the IFC report on low-cost housing

Acknowledgments

Attending MIT has been an incredibly rewarding personal and professional experience. Especially, working alongside and learning from exceptional individuals at MIT, many of them fellow peers of the System Design and Management (SDM) program, who were a constant source of knowledge, inspiration, and an example of living a purposeful life. Undoubtedly and fortunately, some have become lifelong friends.

I would like to recognize Professor Richard De Neufville, for his prominent personality, pragmatic wisdom, and loyalty to his students; David Niño, for his empathy, dedication to his work, and ability to convey through his actions the leadership he teaches in his courses; Joan Rubin, for her unwavering willingness to look out for and motivate SDM students, thanks to her charismatic, commonsensical, and candid yet kind style that makes her an authentic and trustworthy program leader; and my thesis advisor, Professor Christoph Reinhart, for his legacy and commitment to make a better world through his work[3].

Beyond MIT, I ought to thank Siemens Mexico and several of its leaders who have supported and sponsored my continuous development. Distinctly, Marco Cosio, Marco Burgos, Miguel Guerrero, Javier Ibarra and Jair Mexia have shared with me, throughout the years, some of their advice and hard-earned lessons. Moreover, they have gifted me their trust, for which they have my appreciation and loyalty.

I am indebted to those who have been a huge positive influence in my life. To Carlos Perelman, my professor at Universidad Panamericana, for unveiling – through his words, but most importantly his actions – what true leadership is; to my father, for his admirable integrity, loyalty,

[3] A notable example of MIT's motto, *mens et manus*.

humbleness, and intellectual curiosity; to my mother, for her unfaltering trust, love, joy and unbreakable spirit; to my grandmother Eva; for her adaptability, impeccable distinction, tireless commitment to work and learning, and distinct ability to be a unique source of peacefulness – May her memories and exemplary life remain an indelible presence in our minds and manifest through our actions to build a better world.

Most importantly, I thank my wife, Carolina, for her sincerity, optimism, love of life and resolute commitment to her family. Her positive energy has been fuel to double down on our goals and motivation to always persevere. These past years became the best initial chapters to a meaningful journey together.

Finally, I am deeply grateful for the life of our newborn, Elena, for bringing our family joy, light, bliss, and a new layer of meaning to our lives.

To you all, my endless gratitude.

Table of Contents

List of Figures

List of Tables

Glossary

Affordable housing "(…) the US HUD defines the term affordable housing as, the housing that costs no more than 30 percent of a household's monthly income that means rent and utilities in an apartment or the monthly mortgage payment and housing expenses for a homeowner should be less than 30 percent of a household's monthly income to be considered affordable." Chohan et al (2015)

Quality housing – "(…) the (Housing Corporation England, 2007) defines good quality housing design as, the delivery of desirable, affordable, high quality homes and environments that utilise innovative approaches to satisfy the needs and help address the aspirations of occupiers and the wider community." Chohan et al (2015)

Substandard housing – *Substandard* is defined by the Cambridge Dictionary as "below a satisfactory standard", hence it is dependent upon an established set of criteria (as is typically the case with *quality*), which may vary between sources. In relation to housing, UN Habitat is one of the institutions that provides a commonly accepted and used definition[4] for *inadequate* (or substandard, also frequently used interchangeably) housing.

Sustainability – "Meeting the needs of the present without compromising the ability of future generations to meet their own needs." – United Nations Brundtland Commission (1987)

System thinking – "System thinking is, quite simply, thinking about a question, circumstance, or problem explicitly as a system – a set of interrelated entities (…) System thinking can be used in a number of ways: to understand the behavior or performance of an existing system; to imagine what might be if a system were to be changed; to inform decisions or judgements that are of a system nature; and to support the design and synthesis of a system, which we call system architecture." Crawley et al (2016)

[4] See UN Habitat report (page 13)

Acronyms

ACV *Herramienta para el Análisis de Ciclo de Vida* (Lifecycle Analysis Tool)
BREEAM Building Research Establishment Environmental Assessment Method
CASBEE-UD Comprehensive Assessment System for Building Environmental Efficiency – Urban Development
CENAPRED *Centro Nacional de Prevención de Desastres*
CIDOC *Centro de Investigación y Documentación de la Casa* (Center for Housing Research and Documentation)
CSC Critical Success Criteria
CSIRO Commonwealth Scientific and Industrial Research Organisation
DEEVI *Diseño Energéticamente Eficiente de la Vivienda* (Energy Efficient Housing Design)
DENUE *Directorio Estadístico Nacional de Unidades Económicas* (National Economic Units Statistical Directory)
ECUVE *Evaluación Cualitativa de la Vivienda y su Entorno* (Qualitative Evaluation of Housing and its Environment)
EUSI European System of Social Indicators
FOVI *Fondo de Operacion y Financiamento a la Vivienda* (Housing Financing and Operation Fund)
FOVISSSTE Fondo de la Vivienda del Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado (The Institute of Social Secutiry and Social Services Institute for State Employees Housing Fund)
GBI Green Building Index
GHG Greenhouse gas
GIZ *Deutsche Gesellschaft für Internationale Zusammenarbeit* (German Development Cooperation)
HEEVI *Herramienta de Evaluación del Entorno de la Vivienda* (Housing Environment Evaluation Tool)
IDG *Indice de Desempeño Global* (Global Performance Index)
INEGI *Instituto Nacional de Geografía y Estadística* (National Institute of Statistics and Geography)
INFONAVIT *Instituto del Fondo Nacional de la Vivienda para los Trabajadores* (Institute of the National Fund for Workers' Housing)
IRS Internal Revenue Service
KSPI Key Sustainability Performance Indicators
LCA Life-cycle Assessment
LEED-ND Leadership in Energy and Environmental Design – Neighborhood Development
LIHTC Low Income Housing Tax Credit
NAMA Nationally Appropriate Mitigation Action
NatHERS Nationwide House Energy Rating Scheme
ReSOLVE Regenerate, Share, Optimise, Loop, Virtualise, Exchange – A framework of the Ellen MacArthur Foundation
RUV *Registro Unico de Vivienda* (National Register of Housing)
SAAVI *Simulador de Ahorro de Agua en la Vivienda* (Housing Water Conservation Simulator)

SBTOOL Sustainable Building Tool
SEDATU *Secretaría de Desarrollo Agrario, Territorial y Urbano* (Secretariat for Agrarian, Land and Urban Development)
SESNSP *Secretariado Ejecutivo del Sistema Nacional de Seguridad Pública* (Executive Secretariat of the Public Safety National System)
SHF *Sociedad Hipotecaria Federal* (Federal Mortgage Society)
SOFOL *Sociedad Financiera de Objeto Limitado* (Limited Purpose Financial Company)
UNDP United Nations Development Programme
UNFCCC United Nations Framework Convention on Climate Change
UN-Habitat United Nations Human Settlements Programme
US HUD United States Department of Housing and Urban Development
VOC Volatile Organic Compounds

Introduction

A house is a machine for living in. Baths, sun, hot-water, cold-water, warmth at will, conservation of food, hygiene, beauty in the sense of good proportion.

– Le Corbusier (Towards a New Architecture)

To see dwelling as a machine (…) an assemblage of elements coming together in a consistency, namely, the boundary of a dwelling. It is precisely this sense of an assemblage that we see in (…) Le Corbusier when we talks of a house as (…) something that is made up of a collection of elements which become significant when made into a whole. This then has a function of itself: 'a house is a machine for living in' *(…) These notions of the machine, therefore, imply a form of determinism based on the material, of the machine as a limiting and containing form, which imposes an order and an organisation forced by the coming together of its constituent elements*.

– Peter King (In Dwelling, Implacability, Exclusion and Acceptance)[5] – p. 51)

[5] See book (page 51)

Prelude

In 2014, McKinsey & Co. alerted through their "A blueprint for addressing the global affordable housing challenge" report[6], that "by 2025 the number of households that occupy unsafe and inadequate housing or are financially stretched by housing costs could reach 440 million—or 1.6 billion people."

The reader may be alarmed by that figure and then, could reasonably be expected to ask, what is affordable housing? The same report would explain that it might depend on the context but suggests that one could typically assume that it derives from three common criteria, namely: Low income, affordability, and decency standard[7].

Specifically, the report defines provide a definition for each, quoted hereby:

Low income (households): "(…) those that earn 80 percent or less of the median income in the area (…)"
Affordable: "To be affordable, housing must not consume so much of the household budget that there is not enough left to pay for other essential items such as food or healthcare. Most often, an affordable cost of housing is defined as no more than a certain percentage of pre- or post-tax income. Typically, 30 percent of income is regarded as a reasonable limit, and we use that in our calculations (…)"
Decency standard: "A decent dwelling unit has a minimum floor-area (as determined by standards that are socially and politically acceptable) for each household member, includes basic amenities, adequate heating (if relevant), plumbing, and electrical systems, and has no damage or structural defects that can cause health or safety issues (such as broken windows, missing flooring, or holes,

---

[6] See McKinsey & Co. "A blueprint for addressing the global affordable housing challenge" report.

[7] See pages 34-35.

cracks, or leaks). Centers of employment must be within reasonable commuting distance via relevant modes of transportation for the income segment – usually a maximum of one hour away. School and health facilities also must be within short distance, which will vary according to location. UN-Habitat, whose mission is to promote sustainable settlements and adequate shelter, defines substandard housing as dwellings that do not meet any of five basic criteria: durability of structure, sufficient living space, access to safe water, access to sanitation, and security against eviction." McKinsey & Co. (2014)

The report also states that the affordable housing shortage mainly affects developing countries within Asia, Africa and Latin America[8]. It notes that trying to bridge the gap would require several trillion dollars[9] and provides four key levers paired with actions that could help do so: "Land – unlocking land supply, Development – taking an industrial approach, Operations and maintenance – achieving scale efficiency, Financing – reducing cost and expanding access." McKinsey & Co. (2014)

Of course, the report sheds some light on what seem to be recurrent sources of the problem across different cities and countries, and perhaps more importantly, why it matters that society addresses – creating awareness and channeling resources – to the problem based on the major benefits that access to *quality* housing provides[10].

If we accept these benefits as credible – and perhaps, self-evident – it is then clear that providing quality housing would constitute a powerful enabler of social progress and equity.

We have earlier quoted that UN-Habitat considers five elements to define *substandard* housing,

[8] See page 37.
[9] See pages 41-42.
[10] See page 44.

but would the opposite be true? I.e., Could we establish that housing with a durable structure, sufficient living space, access to safe water, access to sanitation, and security against eviction could be considered as *quality* housing?

Even more broadly, should those five criteria become the gold standard to define – and then measure the performance of, based on *figures of merit* – *quality* housing?

More ambitiously, should those criteria become the archetype to inspire policy makers, public or private to inform how to build and what constitutes *quality* housing?

You never cure structural defects; the system corrects itself by collapsing.

– Nassim Nicholas Taleb

Personal Motivation

"This is a story about us, the *indoor generation*. A generation that spends 90% of its life indoors..." Beyond being the opening line of a brilliant ad [11]– which alerts its audience about the consequences of spending too much time indoors without adequate air ventilation and daylight – it is a startling reminder of how much we've become an indoor species.

Catalyzed by the COVID pandemic, homes in urban environments – arguably more than ever in the past century – have become the main setting of our lives, becoming the place where we sleep, eat, work, relax and, essentially, find shelter, safety, and comfort.

From any perspective related to the human condition, access to *quality* housing has commonly been one of the most fundamental needs for a dignified life. Moreover, as our planet becomes warmer and outdoor temperatures become unbearable it is, or will be depending on the region, an even more critical one. Thus, I believe it becomes a moral mandate for societies – with support from both public and private entities and individuals – to support the effort of providing *quality* housing.

Personally, I found that a deceivably simple question (what constitutes *quality* housing?) unveiled a complex, large, systemic problem which evolved into this thesis' *raison d'être* – both as an opportunity to apply the lessons learned from the System Design and Management program and as a source of continuous learning for both my personal and professional interests. My main hope is that the set of criteria established in Chapter 2, will be further improved based on the results after of its tangible implementation, allowing for a combination of theoretical and empirical work.

[11] See Velux [The Indoor Generation] ad in Youtube.

The Plan is the generator.
Without a plan you have lack of order, and wilfulness.
The Plan holds in itself the essence of sensation.
The great problems of to-morrow, dictated by collective necessities,
put the question of "plan" in a new form.
Modern life demands, and is waiting for, a new kind of plan
Both for the house and the city

– Le Corbusier (Towards a New Architecture)

Purpose

The purpose of this thesis is not to provide a theoretical and final answer based on what constitutes *quality* housing, since it is not based on an all-encompassing multivariable optimization algorithm – considering we do not necessarily know what to optimize for – or other mechanisms that process a staggering amount of data and yield countless design alternatives.

On the contrary, this thesis analyzes multiple papers from authors with extensive knowledge on the topic – after providing a brief summary of the status quo of affordable housing in Mexico – that intend to provide a framework that defines affordable *quality* housing and chooses a set of criteria from these sources.

The underlying aim is to address the need to build affordable *quality* housing in Mexico, Latin America, and ideally have it translatable to other low income geographies, by enabling stakeholders directing public-private housing projects (builders, planners, officials, etc.) to assess and compare the performance of affordable *quality* housing design, using the set of criteria chosen[12].

Research Approach

The thesis addresses the following research questions:

1. What criteria are used in academic literature to define *quality* housing?
2. What working set of criteria can we choose to use to define *quality* housing for the purpose of assessing the performance of housing design concepts?
3. What are the limitations of the chosen set of criteria that can be further addressed?

[12] Emphasize the importance of the built environment on global sustainability, regarding both existing and future.

Mass-production is based on analysis and experiment.
Industry on the grand scale must occupy itself with building and establish the elements of the house on a mass-production basis.

We must create the mass-production spirit.
The spirit of constructing mass-production houses.
The spirit of living in mass-production houses.
The spirit of conceiving mass-production houses.
If we eliminate from our hearts and minds all dead concepts in regard to the houses and look at the question from a critical and objective point of view, we shall arrive at the "House-Machine", the mass-production house, healthy (and morally so too) beautiful in the same way that the working tools and instruments which accompany our existence are beautiful.

Beautiful also with all the animation that the artist's sensibility can add to severe and pure functioning elements.

– Le Corbusier (Towards a New Architecture)

Context

Mexico's housing stock and prevalent definition of *quality* housing

Based on official figures[13], Mexico's housing stock in 2003 was comprised of 24.4 million units. Almost 4.3 million units (~17.5%) were categorized as *substandard* housing– which require restoration and/or expansion (~58%), or simply replacement (~42%) by new units.

Before going further into the causes underlying the existing *substandard* housing in Mexico, the report reminds the reader the prevalent ten criteria to define (minimum) *quality* housing (if all ten are fulfilled), guided by three main categories: materials, space, and services, as follows:

Table 1 INFONAVIT's affordable housing quality criteria

Category	Subcategory	Criteria
Materials	Floor	The floor has a slab surface, i.e. something on top of soil
	Roof	The roof is made of durable materials, such as concrete or brick
	Walls	The walls are made of durable materials such as concrete, brick, or stone
Space	Bathroom	The house has at least 1 bathroom
	Kitchen	The kitchen is independent, i.e. not used also as a bedroom
	Overcrowding	There are less than 2.5 people per bedroom
Services	Electricity	There is access to electricity
	Gas	There is access to gas for cooking
	Sewage	There is access to sewage or a septic tank
	Water	There is access to potable water

Therefore, *substandard* housing consists of a failure to fulfill the criteria or do so only partially.

[13] Reported by CIDOC first housing report published in 2004.

Based on how many criteria *substandard* housing lacks, a different course of action is suggested. Housing units lacking between 1 and 3 criteria, are considered to need only minor restoration; between 4 and 6 criteria, should be subject to moderate restoration, and only those failing to meet over 7 criteria are deemed to need major restoration or replacement.

Interestingly, the report provides further detail about the specific deficiencies of the *substandard* housing, based on INEGI's census performed in the year 2000. As can be seen in Appendix A, data showed that the three most common deficiencies were: no access to potable water (49%), *overcrowding* (41%) and the lack of a roof made of durable materials (39%).

Mexico's major housing institutions and their housing expansion attempt in the early 2000s

While this problem was not new at the time of CIDOC's first report – Herbert, Belsky and DuBroff (2012)[14] recall that the FOVI "was established in 1963 as a trust fund to channel federal government money and donations and loans from the World Bank to housing", followed by the establishment of the SHF, which "was chartered in 2001 as a federal development bank backed by the full faith and credit of the federal government (…) SHF acts as a second-tier bank and so does not have a retail operation, but rather channels funds through financial intermediaries such as commercial banks, SOFOLs, and microfinance companies." – it might be fair to say that the government addressed the problem with renewed emphasis and a significantly larger pool of resources – what we'll call the affordable housing expansion attempt – since the beginning of the early 2000s.

A significant majority of efforts were undertaken through both INFONAVIT and FOVISSSTE, described by the same authors, Herbert, Belsky and DuBroff (2012), as the "publicly-mandated

[14] See page 4.

agencies created in 1972 with the goal of creating dedicated sources of housing finance for private and public sector workers, respectively", which comprise the two largest "housing funds" sources in Mexico.

According to Reyes (2020), INFONAVIT showed tremendous growth in their operations in roughly a decade, when mortgages issued every year grew from "more than 250,000 in 2001, 500,000 in 2011, and almost 700,000 in 2013".

It is also relevant to note from her analysis, that a few companies became the major beneficiaries of this expansion, which "allowed the six largest housing development companies to produce approximately 50% of the country's new housing and to operate in most Mexican cities. By specializing in lower and middle-income housing construction, most of them reached their peak around 2007, when they were each selling approximately 50,000 units a year (SHF, 2007)."

In parallel, Herbert, Belsky and DuBroff (2012), explain that part of – they also recognize the role of macroeconomic stability until the 2007 recession – this operational expansion was due to both institutions implementing operational efficiencies that reduced the amount of their non-performing loans, the increased incentives provided to employers to expand the volume of funds secured for workers, the engagement of private lenders to increase borrowing options, all of which led to a significant increase in volume of available loans from these institutions.

Mexico's deficient results of the affordable housing expansion attempt in the early 2000s

One could expect that this impressive growth showed by the affordable housing expansion attempt would have had a positive spillover effect in reducing the stock of *substandard* housing in the country. Nevertheless, CIDOC's 2021 report[15] provides sobering figures. Almost a quarter (~8.5 million units) of the housing stock in Mexico, now comprised of roughly 35.8 million units[16], is qualified as *substandard* housing. About three quarters of *substandard* housing units lack a roof made of durable materials, about the same percentage are overcrowded and less than a quarter lack access to potable water. On the bright side, less than 5% lacked access to either sewage or a septic tank and only about 1% had no access to electricity.

While it could be expected that the proportion of *substandard* housing would be hard to decrease in absolute terms – considering that Mexico's population grew by about a quarter in two decades, from roughly 98 million in 2000 to slightly above 125 million in 2020, which explains the significant increase of the housing stock in the same period – it is surprising to note that, proportionately, it did not decrease either, despite the considerable efforts by the corresponding institutions mentioned above.

After acknowledging that some progress was made, the aforementioned authors also shared their conclusions on why the shortage of affordable *quality* housing remains a significant challenge. Herbert, Belsky and DuBroff (2012) subtly describe several elements that reveal what seems to be a common denominator, addressing only a few elements or stakeholders of the problem, while completely ignoring others (for example, providing financial opportunities to only a small fraction of lenders):

"While INFONAVIT and FOVISSSTE have greatly expanded their lending volumes, and focused a substantial portion of their efforts on workers making between two and four times the minimum wage, there are still many workers with incomes below these levels who cannot afford new homes in the formal sector (…) Another pressing issue is the need to expand borrowing options for the

[15] See pages 83-85
[16] Based on data gathered by Mexico's INEGI census performed in the year 2020.

more than 11 million households who are both unaffiliated with either of the national housing funds and who do not currently have a mortgage".

Failure to apply system-thinking explains affordable housing expansion attempt deficiencies

The affordable housing expansion attempt also failed in many instances to consider that a housing unit is only a small boundary within a large complex system – the technical, social, economic urban system – that needs to carefully integrate and manage several interfaces – utilities, healthcare and transport infrastructure, access to public spaces, job opportunities, and community connections, etc. – for families to thrive.

Therefore, rather than a complex system yielding the desirable emergent properties, the undesirable – although perhaps hardly unexpected – occurred:

"A complex array of factors have combined to drive new housing production in both the informal and formal sectors to far-flung locations removed from employment and social networks, lacking adequate schools and health services, and costly to tie into urban utility grids" transforming the initial condition into an even more complicated one that will require more resources and an aligned course of action from multiple levels of government: "Remedying this pattern will require concerted actions involving federal, state, and municipal governments to identify appropriate locations for development to occur, to invest in the infrastructure needed for these developments, to enhance legal and regulatory regimes to deter irregular settlements, and to create the financial incentives for homebuyers and homebuilders to support more sustainable housing." Herbert, Belsky and DuBroff (2012)

Reyes (2020) provides a more succinct and incisive conclusion of the situation:
"Mexico's housing finance model has been unable (or unconcerned) to assist households with the

greatest housing needs. Moreover, it has fostered a mismatch between housing demand and supply. The impulse to produce housing at great quantities and speed, and the lack of competition and risk at the outset, led to the production of a lot of very poor-quality housing that did not properly address housing shortages. Rather, this development model reproduced overcrowding in minuscule units, structurally deficient dwellings and infrastructure, limited access to services, vacancy, and abandonment. But perhaps even more importantly, such issues were accompanied by a default-prone system that has more recently led to evictions, repossessions, and the auctioning of INFONAVIT's delinquent portfolio to the private sector (at a fraction of its original cost) to rehabilitate and resell it."

It is clear from Reyes (2020) explanation how different stakeholders' incentives played a role in the resulting disarray of the affordable housing expansion attempt, that prioritized maximizing its quantity with barely any regard for *quality*:

"This production system required an elaborate institutional framework to function. INFONAVIT led the way through mortgage expansion and its financial power, made possible by a compulsory levy on workers earnings (and high-interest loan repayment). This great financial engine – along with the important support and incentives provided by pro-development state governments – steered housing development through the peri-urban fringes of Mexico's urban and economic centers. A select handful of real estate developers were handed a front seat in an attractive risk-free business venture to build cheap housing on cheap land that would allow them to maximize profits and amass power. Meanwhile, municipal governments took the back passenger seat. Their low fiscal and institutional capacities and short-term vision drove them to see construction permits as a great revenue stream, without foreseeing the challenges that future administrations would face to provide services and maintain infrastructure. Prospective homeowners almost missed the train and had to adapt to the developers' production systems, centered on producing more and more units to keep the engine running – and to give positive reports to investors."

What seemed like a promising market where every stakeholder was supposed to win: low-income families would receive a new home; municipal governments would receive income from issuing construction permits; real estate developers would increase their revenues; investors would benefit from profiting of what they considered low-risk assets; and the federal government –more specifically, the ruling party – could reap political benefits from boasting a successful affordable housing program and providing an impulse to the economy from increased activity in the construction sector (with a bit of luck, perhaps even collecting more taxes due this additional growth), turned out to be an ill-motivated effort to benefit a handful of developers and the politicians enabling them.

It is questionable that for over a decade, government-backed entities produced housing units of dubious quality, even judged by their own ten criteria – overcrowding not only did not improve but even worsened, based on the data comparison between both censuses performed in 2000 and 2020 – but this is hardly surprising. For starters, one could assume deficient or corrupt enforcement from the government to validate construction standards, especially considering the incentives that both developers and government officials from multiple levels had to opt for quantity rather than quality.

Mexico's INFONAVIT implements measures to improve and mitigate undesirable results

After shortcomings of the affordable housing expansion attempt were identified and increasingly published by several authors and journalists, such as those cited above, some modifications were implemented to bridge the gap between expectations and undesirable results – at least for homeowners. For example, in 2010 INFONAVIT introduced the ECUVE[17] whose purpose and

[17] See Appendix C

criteria will be further discussed within the literature review.

Additionally, at the end of 2010, Felipe Calderón, then the President of Mexico, announced that all new housing inscribed in the RUV should include *ecotecnologías* (eco-technologies)[18] that would contribute to reduce the housing unit environmental footprint – for example, an on-site solar photovoltaic system, LED lights, thermal insulation, water capture and/or conservation systems and/or appliances, etcetera[19] – thus encouraging developers, especially those financed by INFONAVIT, to build sustainable affordable housing.

Later, as Reyes (2020) explains, in 2013 a step forward to prevent overcrowding – although perhaps not ambitious enough – was achieved when "the government stopped granting credits and subsidies to units smaller than 38 square meters" (roughly 410 square feet). Still, small housing units prevail in Mexico[20].

Also in 2013, the federal government, in collaboration with the German KfW Development Bank and the Inter-American Development Bank[21] started the "ECO CASA" (ECO HOUSE) program, as a NAMA based on the commitments reached by the federal government during the UNFCCC celebrated in 2011 in Durban, South Africa.

The purpose of "ECO CASA" was to contribute to Mexico's efforts in reducing GHG emissions by reducing electricity consumption (while increasing comfort levels for housing inhabitants, and reducing housing operational expenses, namely gas and electricity bills)[22]. Thus, the ECO CASA program would produce low carbon emissions housing using preferential interest rates issued by

---

[18] See article "*La hipoteca verde es una realidad*" published in *Real Estate: Market & Lifestyle*
[19] See SEDATU's document describing the *Hipoteca Verde* (Green Mortgage)
[20] According to CIDOC's 2022 report, the size of four out of ten housing units in Mexico is between 56 and 100 square meters (603 to 1,076 square feet).
[21] Both institutions provided a credits lines of ~100 and ~50 million, respectively
[22] See the press report published by GIZ

Mexico's SHF. To achieve its purpose, the program set the goal of building 27,600 housing units by 2020, to mitigate the emission of 1 million tons of CO_2 during a forty-year period – truth be told, an utterly negligible figure for such time interval[23].

With support from the German government, including the GIZ, and international experts and universities, the federal government sanctioned the development of simulation tools and set of metrics[24] – such as SAAVI, to assess water consumption and optimization alternatives, and DEEVI – to evaluate the performance of ECO CASA sponsored housing and enable not only a qualitative but quantitative comparison against regular housing. Later, SAAVI and DEEVI together, became known as the IDG – designed to "convey the energy and environmental performance of housing in a simple and friendly way"[25].

A decade later after its inception, the federal government boasts ECO CASA success[26] while, in parallel, strives to reduce its inherent limitations – very similar to those discussed earlier about the affordable housing expansion attempt – by including two additional simulation tools and sets of metrics – namely HEEVI, introduced in 2017[27] to avoid assessing only the *quality* of housing *per se* (while disregarding infrastructural, environmental, economic and social interfaces with its urban system), and ACV (apparently introduced in 2018)[28], to assess the embodied carbon content of materials (mainly roof, walls and windows) – to better assess the environmental performance of ECO CASA housing.

It is necessary to clarify that the previous summary is not – and does not intend to be – an

---

[23] Roughly, the equivalent of emissions mitigated (compared to the grid's ~0.4 tCO_2e/MWh), during the same 40-years interval, by a ~40 MW solar PV system (assuming a 20% load factor, less than 1% annual yield degradation)
[24] See the foundational document
[25] See SEDATU's document describing the *Hipoteca Verde* (Green Mortgage)
[26] See the press release published by SHF
[27] See RUV's webpage
[28] See the press release published by SHF

exhaustive chronicle of public policies that have shaped the current status quo of affordable housing in Mexico, nor a comprehensive list of its achievements and shortcomings, but merely a compilation of elements that may allow the reader to grasp the context of the thesis and the perennial gap of affordable – and *quality* – housing in Mexico (and some of its veiled context).

Thesis Structure

Chapter 1: This chapter addresses the first research question (What criteria are used in academic literature to define *quality* housing?), reporting the findings from the literature review while revealing some nuances beneath what *quality housing* is.

Chapter 2: This chapter addresses the second research question (What working set of criteria can we choose to use to define *quality* housing for the purpose of assessing a design concept?) and provides a working set of criteria to assess what *quality housing* is, based on the comparisons and conclusions drawn from the literature review analyzed in Chapter 1.

Chapter 3: This chapter addresses the third research question (What are the limitations of the chosen set of criteria that can be further addressed?), providing further sources to curtail the identified limitations.

Chapter 4: This chapter shares some final thoughts about the thesis and brief conclusions.

Chapter 1 – Landscape & Foundation

A great epoch has begun.
There exists a new spirit.

Industry, overwhelming us like a flood which rolls on towards its destined end, has furnished us with new tools adapted to this new epoch, animated by the new spirit.

Economic law unavoidably governs our acts and our thoughts.

The problem of the house is a problem of the epoch. The equilibrium of society to-day depends on it.

Architecture has for its first duty, in this period of renewal, that of bringing about a revision of values, a revision of the constituent elements of the house.

– Le Corbusier (Towards a New Architecture)

Literature Review

Performing this literature review identified an abundance of sources discussing housing from multiple perspectives. The labels (adjectives) to describe housing that served as key search words to find relevant sources were *sustainable*, *affordable*, and *quality*. Interestingly, the first two were repeatedly present in the literature, yet *quality* was commonly absent.

The following selected texts do not compose a full-scale or encyclopedic body of knowledge, they are rather singled out since they provide a particular input about what constitutes *quality* housing, presented as a framework – five of them stem from work performed by academics and practitioners, while the last one presents INFONAVIT's ECUVE[29] evaluation.

Finding other sources – presented in Chapter 3 – was necessary to address specific limitations of the frameworks – both hereinafter discussed – and to enhance the set of criteria listed in Chapter 2.

[29] See Appendix C

A systemic framework to envision housing and its circular economy potential

The *Circular Economy in the Built Environment* report published by ARUP, starts by providing a brief reminder of how relevant it is to achieve the linear to circular transformation of the built environment, supported by sobering facts: "the engineering and construction industry (…) accounts for 50% of global steel production and consumes more than 3bn tons of raw materials", "the sector is also the largest contributor of waste, contributing more than 30% of global greenhouse gas emissions and consuming up to 40% of all energy", "waste management and disposal costs are huge, swallowing up 30% of construction firms' pre-tax profits" (ARUP, 2016)

The introduction also reminds the reader about the ReSOLVE framework, rightfully acknowledging it as "a key output of the Ellen MacArthur Foundation's research", and then provides tangible examples of how each of the ReSOLVE principles can be or has been implemented in urban systems – summarized in its appendix tables at the end.

Regenerate	Regenerating and restoring natural capital	Safeguarding, restoring and increasing the resilience of ecosystems Returning valuable biological nutrients safely to the biosphere
Share	Maximising asset utilisation	Pooling the usage of assets Reusing assets
Optimise	Optimising system performance	Prolonging an asset's life Decreasing resource usage Implementing reverse logistics
Loop	Keeping products and materials in cycles, prioritising inner loops	Remanufacturing and refurbishing products and components Recycling materials
Virtualise	Displacing resource use with virtual use	Replacing physical products and services with virtual services Replacing physical with virtual locations Delivering services remotely
Exchange	Selecting resources and technology wisely	Replacing with renewable energy and material sources Using alternative material inputs Replacing traditional solutions with advanced technology Replacing product-centric delivery models with new service-centric ones

Figure 3: Adopted from: 'Growth Within: a circular economy vision for a competitive Europe', Ellen MacArthur Foundation, SUN, McKinsey Center for Business and Environment 19

Figure 1 ReSOLVE Framework

Then, the document introduces the 7S Model, after evoking its origins:

“The concept of building in ‘layers’ was first proposed by architect Frank Duffy in the 1970s and developed by Stuart Brand in the 1990s. Buildings, they said, are made of separate and interlinking layers, each with a different lifespan. Brand’s widely known model includes six layers: Site, Structure, Skin, Services, Space, and Stuff. The diagram below illustrates how the layers model would function in the built environment context. An additional layer — System — has been added to show how this approach would be applied beyond the scope of a building, for example in the context of a district or city.

Building in layers means that each element may easily be separated and removed. This facilitates reuse, remanufacture and recycling. For example, facades or heating systems may be designed and fitted as independent entities, integrated with other building systems but not entwined with the fabric of the building. This also avoids large scale wastage of assets, lowers resource use and other environmental impacts, and obviates the need to construct entirely new buildings and assets. Building in separate layers, with different lifespans also allows each element to be repaired, replaced, moved or adapted at different times without affecting the wider entity, e.g. the building or infrastructure asset. This reduces unnecessary obsolescence and increases flexibility of use and longevity over time.” (ARUP, 2016)

It is relevant to note that adding the seventh layer, is a simple yet clever addition to Brand’s model, that recognizes the importance of considering the interfaces between housing and its urban system.

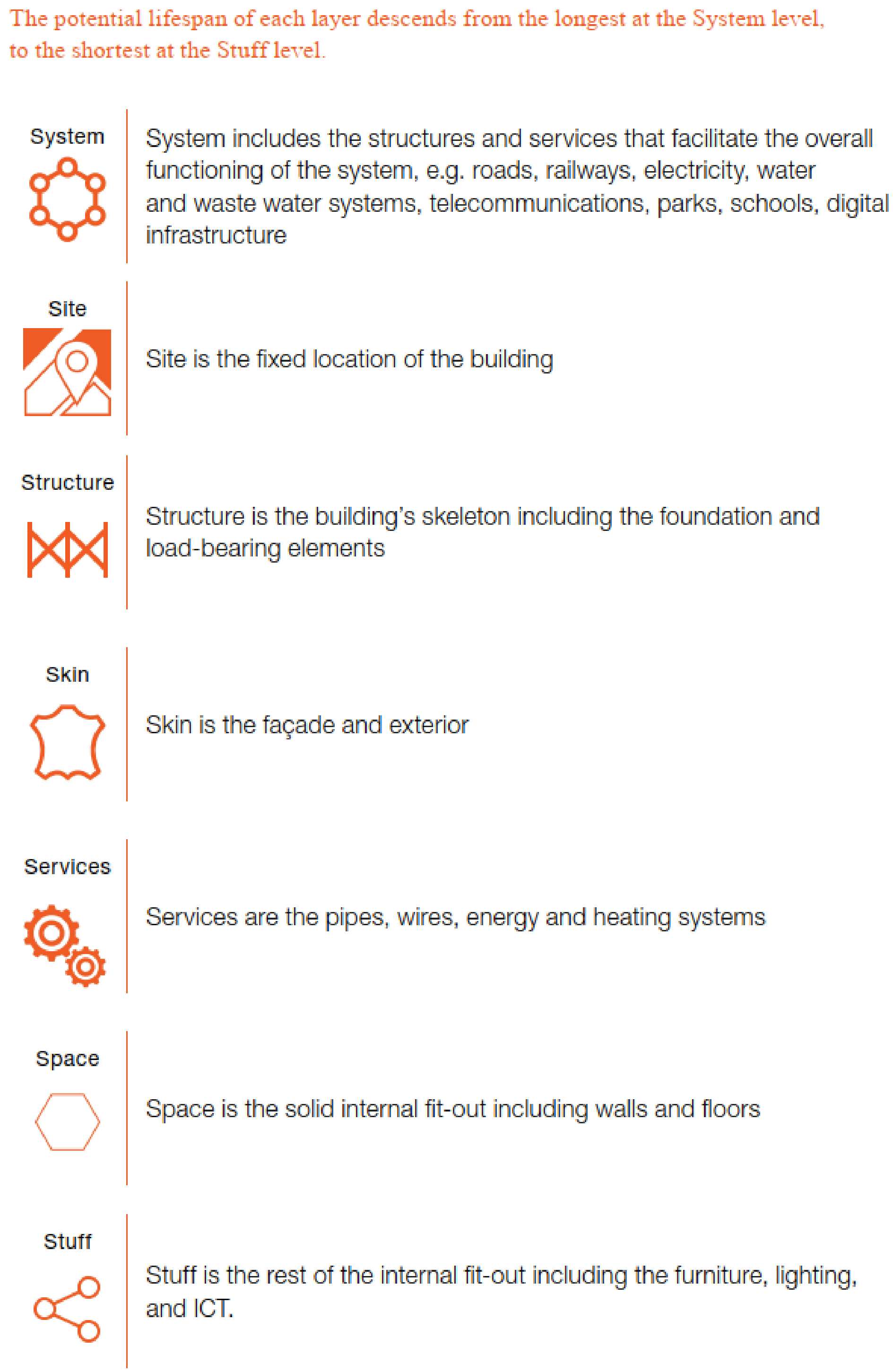

Figure 2 7S Model (Descriptive)

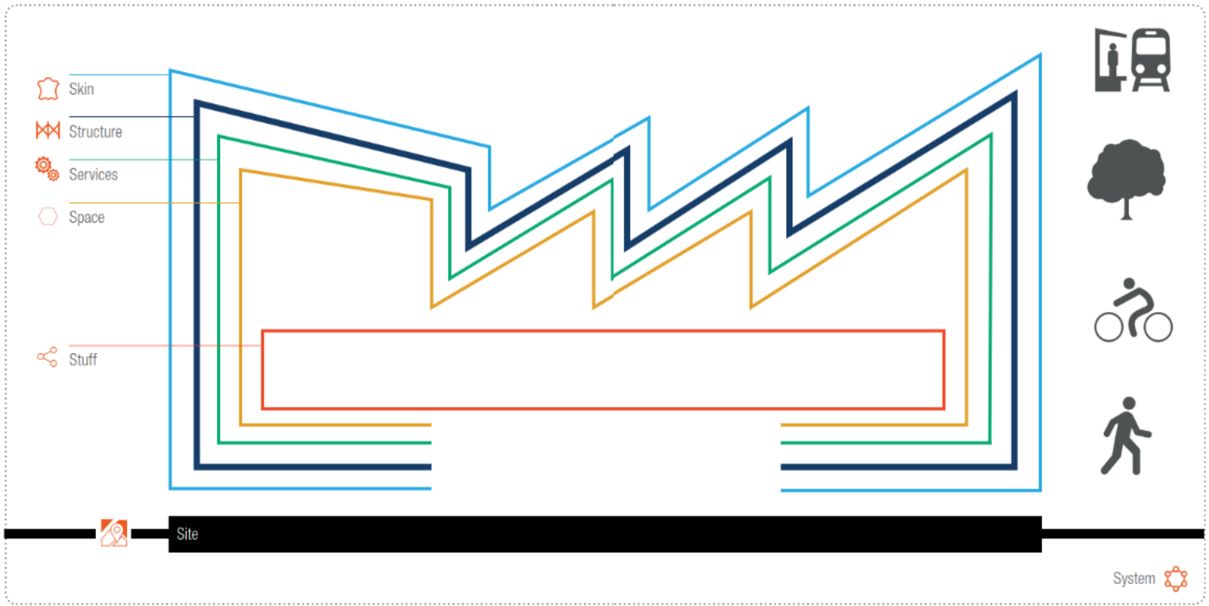

Figure 37S Model (Visual)

A basic environmental evaluation and a preliminary concept of functionality

A paper authored by Velázquez et al (2022), gathers “quantitative sustainability performance indicators” from almost twenty papers published within two decades (between 2001 and 2020) organized in four categories: Economic, Environmental, Social and Functional. The first three, contain indicators that, arguably, represent the bare minimum elements to perform an assessment of affordable housing[30], especially from a developer or sponsor point of view. Yet, the fourth category, includes two indicators that aim to convey the “Modifiability and layout flexibility”.

The first indicator assesses “the flexibility of a building for a future expansion to satisfy users units space needs” Velázquez et al (2022) and it measures the expandability of the housing unit in square meters. I.e., a unit where 50 square meters represent the initial construction but could (and is built to) be doubled, by the addition of a second floor, would score a 100% in incremental facility. In comparison, the second indicator is broadly labeled as *Safety* and specifically as *flood resilience measures*. The description highlights the importance of considering durability and materials

[30] Also referred to in the paper *social housing*

resilience.

Curiously, both indicators are related to uncertainty. Nevertheless, the first is internal, based on the family future needs – that could be influenced, for example, by their living habits and additional family members – while the second is, in this specific case, external – contingent upon weather patterns and their local impact.

It is also relevant to consider that safety could be addressed from many different perspectives, both inherent to the housing unit and/or dependent from its urban system.

REQUIREMENTS	CRITERIA	INDICATORS	OVERVIEW	REFERENCES
R1. Economic	C1 Invest capital	I1 Construction system (including the mechanical, electrical, plumbing installations, and finishes level) (euros/m^2)	Includes all direct costs of the superstructure and standard equipment, such as windows, door, interior walls, kitchen and bathroom furniture. The labour cost is included. The price of the land and urban infrastructure is not included in the initial construction cost.	Alarcon et al., 2001; Aguado et al., 2006; Kunz and Fischer, 2012; Wallbaum et al., 2012; Orihuela et al., 2017: Hosseini et al., 2020
R2. Environmental	C2 Energy efficiency	I2 Energy efficiency (kWh/year/m^2floor)	Include the operational energy for heating, cooling, lighting, domestic water heating and appliances.	Alarcon et al., 2001; Aguado et al., 2006; Botero et al., 2007; Rankin et al., 2008; Constructing Excellence, 2013; Heravi et al., 2015; Kylili et al., 2016; Orihuela et al., 2017; Adabre et al., 2020; Liu et al., 2020; BREEAM, LEED.
		I3 Embodied Energy (MJ/m^2floor)	Include the quantification of all the energy needed to bring the raw material from the extraction to their manufacture and lifting; it includes the energy associated with transport.	
	C3 CO_2 Emissions	I5 Carbon Emissions (tCO_2eq/Year/m^2floor)	Emissions from operation include heating, cooling, lighting, domestic water heating and appliances and these can be direct or indirect. For example, a furnace could be direct (gas-powered), or indirect (electricity-powered).	
	C4 Water consumption	I6 Water consumption (m3/year/m^2floor)	Water consumption during the operational phase of the building. Include kitchen use, bathroom use and washing use.	
R3. Social	C5 Customer satisfaction	I7 Delivery time (days/m^2)	This indicator evaluates the importance of prefabrication, supply chains and management.	Pillai et al., 2002; Wong, 2004; Aguado et al., 2006; Rankin et al., 2008; Geraedts, 2008; Skibniewskil and Ghosh, 2009; CII Construction Industry Institute, 2011; Constructing Excellence, 2013; Orihuela et al., 2017
R4. Functional	C6 Modifiability and layout flexibility	I8 Incremental facility (%)	This indicator assesses in m^2 the flexibility of a building for a future expansion to satisfy users units space needs.	Geraedts, 2008; Wallbaum et al., 2012;
		I9 Safety (Flood resilience measures)	The service lifespan of the house plays a vital role in the creation of local value. Indicators to assess the durability of the building include construction techniques and materials resilient to floods according to the construction regulations of each country.	

Figure 4 Velazquez et al (2022) Quantitative sustainability performance indicators

A peculiar paradigm to assess housing: Critical Succes Criteria

An extract from *Building and Environment: The International Journal of Building Science and Its Applications* written by Chan and Adabre (2019) identified twenty-one *Critical Success Criteria,* i.e., economic and non-economic criteria that are, in their words, "associated with evaluating success of sustainable affordable housing projects" and "the set of principles or standards through which judgement can be made", defined to "help governments and international policy makers on strategies required to bridge the gap between sustainable housing and affordable housing".

The authors describe that their process to collect the twenty-one CSC involved a "comprehensive literature review followed by a questionnaire survey" Chan and Adabre (2019). While categories for the CSC are not provided, it is suggested that "CSC can be grouped into six components: household satisfaction CSC, stakeholders' satisfaction CSC, house operation cost CSC, time measurement CSC, location affordability cost CSC and quality-related CSC." Chan and Adabre (2019)

No.	CSC for Sustainable Affordable Housing	References
CSC01	Timely completion of project	Chan and Chan [23]; Bassioni et al. [22]; Ahadzie et al. [16]
CSC02	Construction cost performance of housing facility	Al-Tmeemy et al. [28]; Osei-Kyei and Chan [33]
CSC03	Quality performance of project	Atkinson [21]; Lim and Mohamed [24]; Cox et al. (2003)
CSC04	Safety performance	Wai et al. [34]; Kylili et al. (2016); Ngacho and Das (2014)
CSC05	End user's satisfaction with the housing facility	Torbica and Stroh [17]; Bryde and Robinson (2005)
CSC06	Project team satisfaction with the housing facility	Yan et al. [35]
CSC07	Environmental performance of housing facility (Eco-friendly)	Lim and Mohamed [24]; Atkinson [21]; Rankin et al. [18]
CSC08	Reduce life cycle cost of housing facility	Wai et al. [34]; Ahadzie et al. [16]
CSC09	Maintainability of housing facility	Wai et al. [34]
CSC10	Energy efficiency of housing facility	Wai et al. [34]; Ahadzie et al. [16]
CSC11	Reduced occurrence of disputes and litigation	Osei-Kyei and Chan [33]
CSC12	Reduced public sector expenditure on managing housing facility	Osei-Kyei and Chan [33]
CSC13	Functionality of housing facility	Chan and Chan [23]; Chan et al. [36]
CSC14	Technical specification of housing	Chan and Chan [23]; Osei-Kyei and Chan [33];
CSC15	Aesthetically pleasing view of completed house	Chan and Chan [23]
CSC16	House price in relation to income	Mulliner et al. [15]; Ahadzie et al. [16]
CSC17	Rental cost in relation to income	Mulliner et al. [15]
CSC18	Commuting cost from the location of housing to public facilities	Hamidi et al. [37]
CSC19	Technology transfer	Ahadzie et al. [16]
CSC20	Waiting time of applicants before being allocated a housing unit	Chiu [38]
CSC21	Take up rate of housing facility (marketability of housing facility)	Pullen et al. [39]

Figure 5 Chan and Adabre (2019) Critical Success Criteria

Interestingly, specific quantitative indicators are not directly provided within each CSC – just some will be found within the referenced sources – and only a few CSC introduce concepts that could be simply quantifiable, including CS09: *maintainability of housing* facility which could be interpreted as the length, frequency and cost of maintenance activities required to maintain a housing unit; CS18: *commuting cost from the location of housing to public facilities*, a clear unearthing of a harsh reality that many low-income households face when living in affordable housing – commonly built in the suburbs [31]– and a salient cause of abandonment.

Other CSC are inherently subjective, either dependent on surveys' inputs (CSC05: *end-user's satisfaction with the housing facility* and CSC06: *Project team satisfaction with the housing facility*); very broad, requiring a context-applicable definition (CS03: *quality performance of project*, CS04: *safety performance*, and CSC19: *technology transfer*) – for example, how flood resilience was used by Velazquez et al (2019) as a measure of safety) – or both (CSC13: *functionality of housing facility* and CSC15: *aesthetically pleasing view of completed house*).

A broad yet incomplete approach to housing

An article included within the Journal of Cleaner Production, by Gan et al (2017), "aims to identify the key sustainability performance indicators (KSPIs), which are useful to guide the development of affordable housing (…) through an extensive literature review (…) followed by a questionnaire survey to solicit the professional views from three stakeholder groups, namely government, developers and academics in the Chinese construction industry" Gan et al (2017).

This analysis is of special interest, considering that China is not only the world's major manufacturer of cement, steel and plastics – i.e., the backbone of construction materials – but also a heavyweight of the construction industry. Revamping the affordable housing sector, by improving its sustainability and quality, using a specific framework influenced by the relevant stakeholders, could transform China into a trendsetter in this field, as happened a few years ago within the renewable energy and climate tech sector.

[31] Or *periurban fringes* as labeled before by Reyes (2020)

Gan et al (2017) provide an initial list of so-called KSPIs, spanning three categories: Economic, Environmental, and Social sustainability.

NO.	Sustainability performance indicators	References
Economic sustainability		
SPI1	Financial viability	(Chiu, 2003; Turcotte and Geiser, 2010)
SPI2	Cost effectiveness	(Isalou et al., 2014)
SPI3	Desirability	(Pullen et al., 2010)
SPI4	Affordable price/renting	(Winston and Montserrat, 2007)
SPI5	Reduced life cycle cost	(Roufechaei et al., 2014)
SPI6	Provide human resource for economic development	(Muazu and Oktay, 2011)
SPI7	Ensure balanced housing market	(Golubchikov and Badyina, 2012)
SPI8	Generate job opportunities	(Chiu, 2003)
SPI9	Reduced transportation cost	(Isalou et al., 2014)
SPI10	Cost recovery	(Isalou et al., 2014)
SPI11	Other non-housing related costs	(Ibem and Azuh, 2011)
SPI12	Reduced energy bills	(Fuhry and Wells, 2013)
SPI13	Integrate related industries of sustainable housing	(Fuhry and Wells, 2013; Ross et al., 2010)
Environmental sustainability		
SP14	Disaster resistance	(Azevedo et al., 2010; Charoenkit and Kumar, 2014)
SPI15	Land use efficiency	(Charoenkit and Kumar, 2014; Winston and Montserrat, 2007)
SPI16	High housing density	(Charoenkit and Kumar, 2014; Dempsey et al., 2012)
SPI17	Mixed land using	(Dempsey et al., 2012; Winston and Montserrat, 2007)
SPI18	Energy efficiency	(Ross et al., 2010; Roufechaei et al., 2014)
SPI19	Water efficiency	(Ross et al., 2010; Roufechaei et al., 2014)
SPI20	Adequate living spaces within small size unit	(Pullen et al., 2009; Winston and Montserrat, 2007)
SPI21	Comfortable and healthy indoor environment	(Chiu, 2003; Winston and Montserrat, 2007)
SPI22	Available green public spaces	(Ross et al., 2010; Winston and Montserrat, 2007)
SPI23	Effective waste management	(Chiu, 2003; Ross et al., 2010)
SPI24	Adaptability and flexibility	(Pullen et al., 2009; Turcotte and Geiser, 2010)
SPI25	Reliability and durability	(Fuhry and Wells, 2013)
SPI26	Effectively utilizing resources	(Ross et al., 2010; Roufechaei et al., 2014)
SPI27	Reduced footprint	(Nissinen et al., 2015; Ross et al., 2010)
SPI28	Minimize biodiversity loss	(Pullen et al., 2009; Tsai and Chang, 2012)
Social sustainability		
SPI29	Accessibility	(Dempsey et al., 2012; Isalou et al., 2014)
SPI30	Equability and fairness of housing distribution	(Chiu, 2003)
SPI31	Cultural and heritage conservation	(Chiu, 2003; Muazu and Oktay, 2011)
SPI32	Community participation	(Ross et al., 2010)
SPI33	Sense of community	(Chiu, 2003; Dempsey et al., 2012)
SPI34	Effective maintenance and management of properties	(Azevedo et al., 2010; Charoenkit and Kumar, 2014)
SPI35	Tenure security	(Azevedo et al., 2010; Winston and Montserrat, 2007)
SPI36	Minimize social segregation	(Chiu, 2003; Ross et al., 2010)
SPI37	Maximize the wellbeing of workers	(Turcotte and Geiser, 2010)
SPI38	Diversified housing types	(Winston and Montserrat, 2007)
SPI39	Social acceptability	(Chiu, 2003; Pullen et al., 2009)
SPI40	Suitability	(Ibem and Aduwo, 2013)
SPI41	Harmonious social relationships	(Chiu, 2003; Mulliner et al., 2013)
SPI42	Increased consciousness of environment protection	(Myerson, 2007)

Figure 6 Gan et al (2017) Key Sustainability Performance Indicators

After applying fuzzy set theory and variance analysis, the KSPIs are narrowed from 42 to 24, maintaining the three categories: Economic, Environmental and Social sustainability.

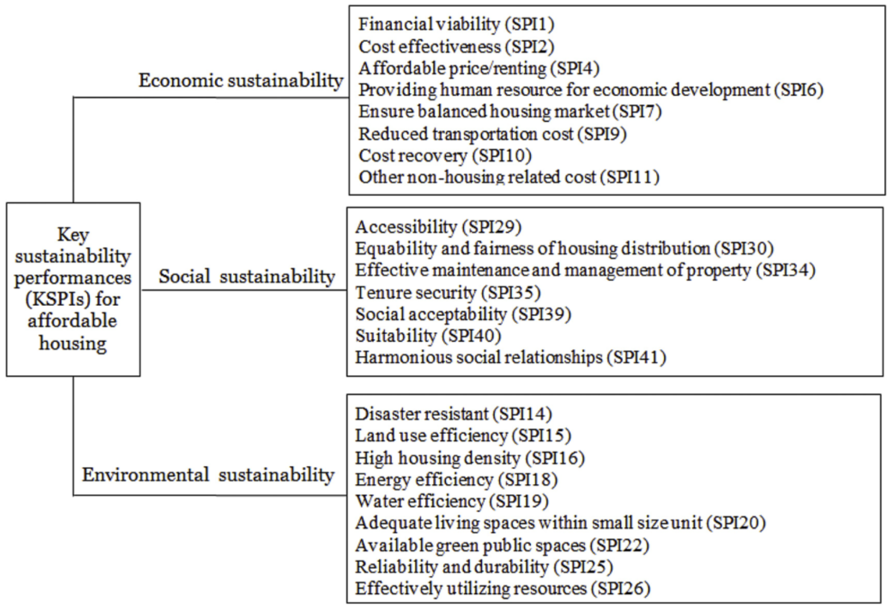

Figure 7 Figure 6 Gan et al (2017) Key Sustainability Performance Indicators (v2)

One could find it reasonable to infer – judging exclusively from their name – the quantitative metrics that would be necessary to evaluate the performance of a housing unit using the Economic sustainability KSPIs – perhaps with the exception of two rather ambiguous measures, *providing human resource for economic development* (SPI6) and *ensure balanced housing market* (SPI7) – whereas it would be much harder for most of the Social sustainability KSPIs – at best excluding *effective maintenance and management of property* (SPI30) which could be based on a set of activities, and its associated length, frequency and costs, to maintain a housing unit – to come up with a specific quantitative metric underlying each KSPI without having its working definition.

For example, what does *Suitability* (SPI40) mean within the affordable housing context and how shall it be measured? (while Ibem and Aduwo (2013), the paper cited by Gan et al (2017) as the source of this KSPI, provides an insightful assessment entitled *Residential satisfaction in public housing in Ogun State, Nigeria*, its text does not even contain the word *suitability* or *suitable*).

Interestingly, only a few of the papers cited by Gan et al (2017) present working definitions that would allow the development of quantitative metrics and, in consequence, assess whether specific housing units exhibit the desired KSPIs mentioned.

For example, Pullen et all (2010) – not to be confused with Pullen et all (2009) – provide useful working definitions of "Affordability" (related to SPI4), "Desirability", "Density and Urban Form" (related to SPI16), "Adaptability", and "Social Acceptability" (related to SPI39). The paper also provides a framework with other interesting inputs that will be discussed also within this literature review.

While one could grasp the quantitative nature of several KSPIs – especially those related to use efficiency: land, water, energy and resources – and even expect to find a range or threshold of desirable results (for example, a housing unit designed to enable a per person per year consumption of water ≤ X number of gallons constitutes an efficient one) without requiring an overly extensive search, finding the desirable – or even acceptable – range or threshold for many Environmental sustainability KSPIs turned out to be rather intricate, even searching through some of the original sources cited by Gan et al (2017). To exemplify, we'll analyze three KSPIs and their cited sources:

Disaster resistance (SP14) – The first source mentioned, Azevedo et al (2010) never mentions any specific instance of *disaster resistance* or similar terms. Their *Indicator's Proposition* – which they acknowledge stems from the SBTool2006 – contains three categories: *Social Dimension*, *Economics*, and *Environmental*". The only indicator arguably resembling *disaster resistance* might be: *Vulnerability of slope stability*, "estimated by the undertaking's situation in relation to the declivities (hills) and the existing protection measures against sliding (slope stabilization). The protection against sliding has specific designs by qualified professionals." Azevedo et al (2010)

Contrastingly, the second source cited, provides an extraordinary review of "five rating tools that are widely applied for assessing environmental sustainability of urban projects, namely, BREEAM-Community, LEEDND, CASBEE-UD, SBTool2012, and GBI for Township (…) to evaluate the effectiveness of such tools in addressing greenhouse gas emission reduction and disaster resilience for low-income housing schemes" Charoenkit & Kumar (2014). Due to its relevance, the whole comparison of indicators from this source (denominated Table 6 within the paper), is reproduced as Appendix B.

Although *disaster resistance* (mentioned within the paper as *disaster resilience*) is indeed a core element of the analysis, their authors criticize the lack of useful metrics: "As demonstrated above, the rating tools have limitations on the application to low income housing in developing countries as the tools substantially rely on local standards, expert evaluation and lack of inclusion of key aspects, especially disaster resilience and financial" Charoenkit & Kumar (2014), considering that specific metrics within the *Disaster planning* category of the reviewed tools are mainly provided in only two of five indicators. Namely, *Evacuation Planning* (a set of dimensions related to the ease of evacuation and shelter) and *Local food* (an ideal range – between 5 and 20 sqm per housing unit – for community gardens that serve as a source of food).

In contrast, the other three indicators – *Risk zone*, *building resilient design* and *utility planning* – are by and large – only BREEAM suggests a minimum floor level of 0.60m within the *Building resilient design* indicator) – dependent upon non-quantitative *compliance with local standards*. Basically, all tools waive their opportunity – an alternative could have been to provide a non-quantitative checklist informed by empirical observation and application – to contribute to this topic, leaving those who want further guidance within a potential vacuum, as the authors accurately remark: "not all building codes incorporate elements of environmental sustainability and disaster resilience, and not all codes are enforced strongly" Charoenkit & Kumar (2014).

Reliability and durability (SPI25) – One could expect to find objective and comparable metrics related to the functionality of materials' properties (for example, compressive strength for cement or other materials used to withstand loads, or even a label that would approximate the values of its properties, such as specifying Portland cement) and the resulting expected lifetime of the housing unit as a whole – before requiring a major retrofit or replacement – to assess reliability and durability, respectively.

However, the only source cited by Gan et al (2017) in relation to this KSPI – an article by Fuhry and Wells (2013) – only mentions an existing trade-off that housing agencies in the U.S. face when building affordable housing, using cheap materials (implying more frequent replacement and costlier maintenance requirements) or the opposite: "The utility and maintenance cost savings over a 45-year period typically outweigh initial savings gained by using cheap materials" Fuhry and Wells (2013) and the underlying incentive that affects the decision:

"LIHTC[32] funded projects must serve low- or moderate-income tenants for 15 to 45 years (…) the long-term nature of the LIHTC program allows housing agencies to factor in these operating and maintenance issues when making construction decisions" Fuhry and Wells (2013).

---

[32] Fuhry and Wells (2013) also provide the reader with a lengthy yet noteworthy description of LIHTC:

"A major catalyst for the greening of affordable housing is the financing tool, familiar to housing insiders but relatively obscure to most other professionals, known as the Low-Income Housing Tax Credit program, Section 42 of the IRS Code.

Created by the Tax Reform Act of 1986, LIHTC financing has since contributed to more than two million affordable rental units that serve individuals and families making 60 percent or less of the area median income. Through the LIHTC program, tax credits are allocated to developers of income-restricted properties. The credits can then be transferred to private investors in exchange for development equity. The ability to attract private equity reduces the need for direct government financing and enables developers to maintain rents at subsidized levels.

Section 42 provides broad parameters for the LIHTC program, but state housing authorities set the specific criteria for allocating the credits. Each year state housing finance agencies set geographic, typology, or amenity priorities; establish minimum construction standards; and create locally significant evaluative criteria in a document known as the Qualified Allocation Plan.

The QAP is then used to score individual project applications. Selected applicants are allocated a set amount of LIHTCs based on the anticipated project cost. Because competition of LIHTC allocations is often highly competitive, the QAP criteria can have a significant impact on what design strategies are included in projects seeking credits."

Still, no quantitative metrics related to measuring *resource efficiency* or *resource conservation* – the terms used in the article – are provided or referenced therein.

Adequate living spaces within small size unit (SPI20) – As in the previous KSPI, one could expect to obtain a working definition of what constitutes *adequate* – conceivably related to the size of and comfort derived from – living spaces within a housing unit and a range or threshold to designate them as *small*. Nevertheless, both are absent within the two sources cited by Gan et al (2017) regarding this KSPI.

First, Pullen et al (2009) do not quantify or define *adequate* living spaces or *small* size unit, yet they mention a common trade-off regarding the *dwelling size* of housing units:

"Increasing floor areas can unnecessarily reduce affordability and environmental sustainability. Conversely minimum floor areas are required for health and well-being." Pullen et al (2009)

After informing the reader about the absence of a "provision within the current Building Code of Australia (2009) for a minimum dwelling size" Pullen et al (2009), a figure conveying an ideal value is shared: "European dwelling standards suggest that on average a minimum useful floor space of 100 square metres is required for a sustainable dwelling" Pullen et al (2009), apparently stemming from empiric evidence: "most European countries with the exception of England and Wales have minimum dwelling sizes. Average useful floor space in Europe is around 100 square metres, with Belgium and Luxembourg having an average floor space of 130 square metres." Pullen et al (2009). Finally, the authors reference other sources[33] on the matter for further comprehension of the topic, but do not add additional context from them.

[33] UK Code for Sustainable Homes, Goodchild, B. (1997), *Housing and the urban environment: a guide to house design, renewal and urban planning* and Oxley & Smith (1996) *Housing policy and rented housing in Europe*.

Second, Winston and Pareja-Eastway (2007) focus on providing a comprehensive review about the evolution of *indicator sets* related to sustainable development (SD), followed by supporting arguments to an initial clam aligned with the purpose of this thesis:

"(…) this article contends that housing is an underdeveloped indicator and calls for more attention to be paid to the importance of aspects of housing for SD and the measurement of progress towards it via social indicators." Winston and Pareja-Eastway (2007)

While the article highlights the insufficiency of several indicator sets, it also acknowledges the EUSI, reproduced herein, since it

"(…) captures many of the important dimensions of sustainable housing – economic, social and environmental. It links sustainability to other important welfare concepts such as social cohesion, and quality of life." Winston and Pareja-Eastway (2007)

Goal dimensions	Measurement dimensions
Availability of dwellings	Relative size of dwelling stock
Size of dwelling	Rooms per person and living space per person (under preparation)
Amenities	Availability of flushing toilet, bath/shower; central heating; balcony, terrace/garden
State of repair of dwelling	Dwellings in deficient state of repair
Tenure status	Percentage of owners
Type of accommodation	Households living in one-family house/in a large apartment house
Affordability of housing	Burden of housing costs; average rent/qm in ppp (under preparation); average rental burden
Facilities in residential area	Accessibility of shops; public transport; family doctor
Environmental quality of residential area	Noise pollution; air pollution; accessibility of green space
Public safety	Crime in residential area
Subjective evaluation of housing conditions	Shortage of space; high burden of housing costs; satisfaction with housing situation
Subjective evaluation of the residential area	Subjective safety in the residential area, Satisfaction with neighbourhood
Regional disparities in housing conditions	Regional disparities in availability of amenities and rental burden
Income related inequality of housing conditions	Income related inequality in: dwelling size; availability of amenities; and tenure status.
Homelessness (data not currently available)	Percentage of homeless people
Poor housing conditions	Overcrowded dwellings; lack of basic amenities
Area used for settlement	Built up land per inhabitant (under prep)
Energy consumption	Use of environment-friendly energy sources for heating; energy consumption for space heating; energy loss per building (under prep); insulation of housing stock (under prep)
Preferences related to dwelling	Need for own room per household member; need for a garden, balcony or terrace; preference for a one family house (data currently not available)
Preferences related to residential area (data currently not available)	Preference for living in rural/urban area

Figure 8 EUSI

Notwithstanding, the EUSI indicators only provide a partial input to the specific KSPI, *Adequate living spaces within small size unit (SPI20)*, indicated by Gan et al (2017)[34] – namely *Rooms per person and living space per person*, *overcrowding dwellings* or *shortage of space* are indicators that can be quantified, yet a threshold or range to complement the indicators, and allow *adequate* living spaces or *small* size unit to be measured, is absent in this paper as well.

Over fifteen years after Winston and Pareja-Eastway (2007) recommended the development of

[34] Incorrectly citing the source as Winston and Montserrat (2007) instead of Winston and Pareja-Eastway (2007)

improved indicator sets for housing units, the European Union (EU) seems to maintain the same *housing condition* metrics, as can be seen within two EU sources:

1. the current *Eurostat datasets*[35] on *Housing conditions* (a subcategory of *Living conditions*)

2. the *Portfolio of EU Social Indicators for the Monitoring of Progress Towards the EU Objectives for Social Protection and Social Inclusion* where *Housing*[36] contains no specific definition, only a comment: "Further work is necessary before the including of an indicator on housing in the primary list." (Publications Office of the European Union, 2015). As expected, the housing *Secondary Indicators* only include *Housing cost overburden rate*, *Overcrowding rate*, and *Housing deprivation by item*.

3. the *Housing in Europe: 2023 interactive publication*[37] – which "shows figures on many different aspects of housing" (Eurostat, 2023) including: *Share of people living in households owning or renting their home*, *Type of housing*[38], *Size of housing*[39], *Average household size*[40], *Overcrowding*[41] and its opposite *Under-occupancy*, *Share of people living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor*, *Greenhouse gas emissions by households for heating and cooling*, and other factors revealing some economic and geographic characteristics of the European housing stock[42].

In summary, this source, expected to include the most comprehensive list of criteria to define *quality* housing, ended up being quite insufficient, in terms of its specificity, thus, applicability.

---

[35] See Eurostat datasets
[36] Labeled as SI-P14 within the "Primary Indicators" list
[37] See report
[38] Categorized as: house, flat, others
[39] Defined as: average number of rooms per person
[40] Based on the average number of persons per household
[41] Defined using the following criteria: "A household is overcrowded if it has at its disposal less than a minimum number of rooms considered adequate: one room for the household, per couple, for each adult single person, per pair of single people of the same gender aged 12-17, for each single person aged 12-17 and not included in the previous category, and per pair of children under 12"
[42] Interestingly, the European Union recently launched the *New European Bauhaus* initiative, promoting the *Davos Baukultur Quality System*, comprised of "Eight criteria for high-quality architecture and a high-quality built environment" (Publications Office of the European Union, 2021). See the report *Towards a Shared Culture of Architecture*, evaluation checklist, assessment form and the whole story.

A practitioner's eclectic and pragmatic framework

As mentioned before, Pullen et al (2010), provide an *Interim Affordability and Sustainability Framework* which "seeks to link indicators of affordability with those of economic, social and environmental sustainability" Pullen et al (2010), derived from their research methodology, including a combination of theoretical and empirical activities:

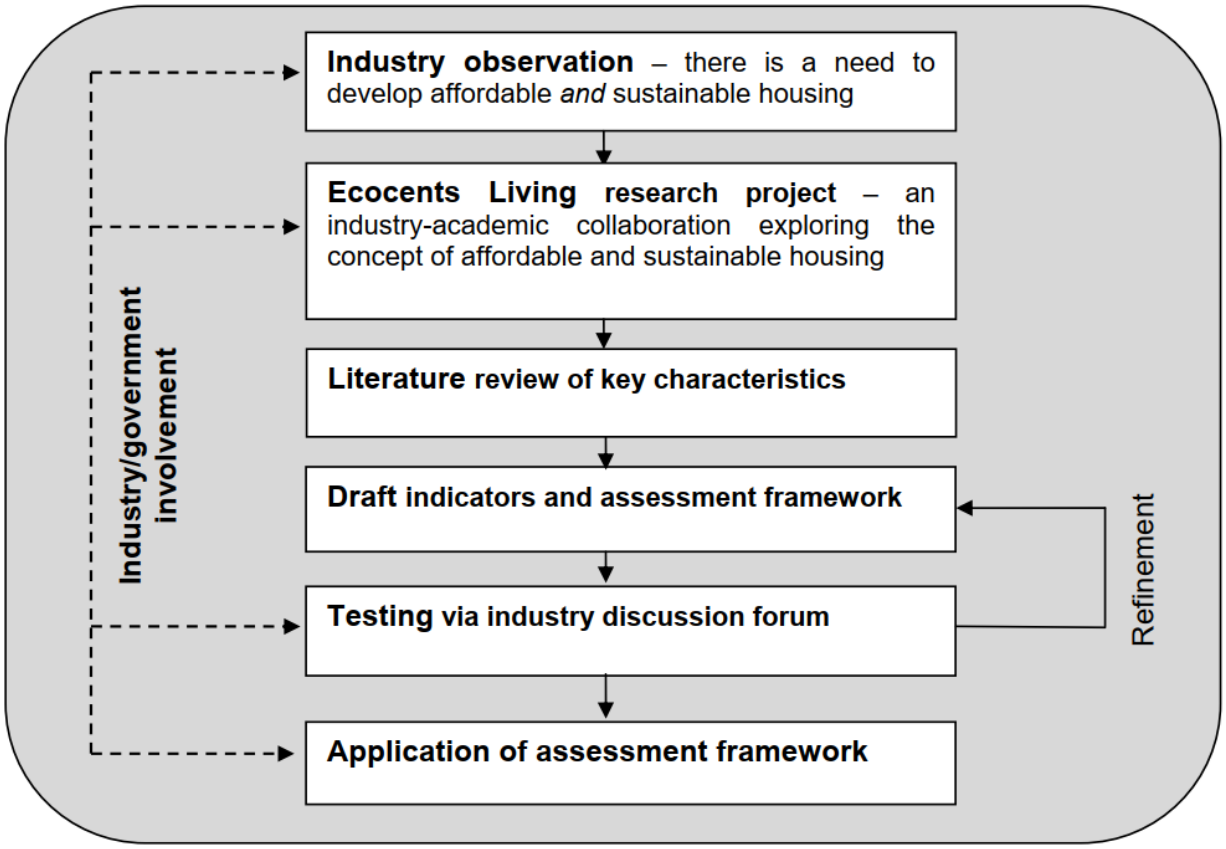

Figure 9 Pullen et al (2010) research methodology

The model aims to fulfill its purpose by "outlining eleven possible performance indicators of affordable and sustainable housing" Pullen et al (2010), namely: Energy (Efficiency), Water (Efficiency), (Construction) Materials, (Construction) Methods, Financial procurement, Affordability, Dwelling size, Appropriate Density, Adaptability, Social Acceptability and Desirability.

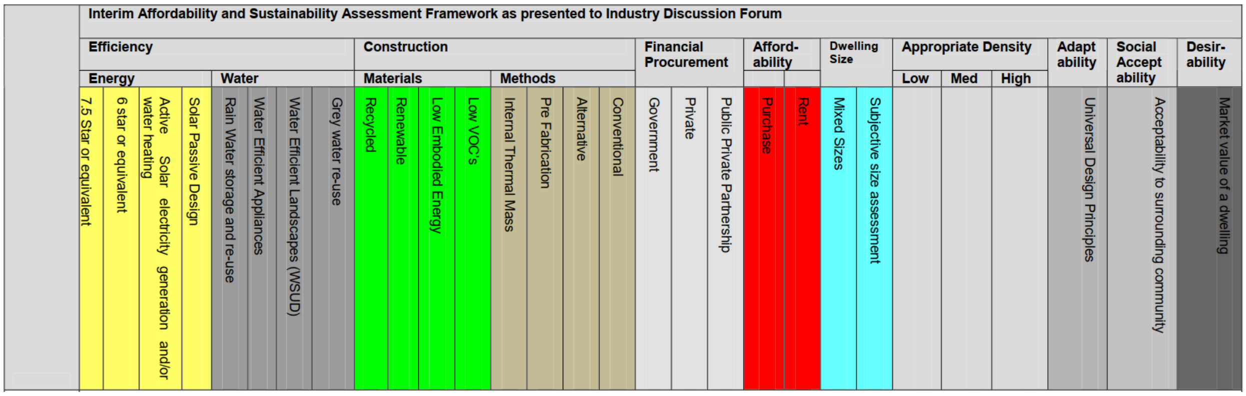

Figure 10 Pullen et al (2010) Interim Affordability and Sustainability Framework

One will quickly realize that the performance measures of the eleven indicators vary in their applicability ease. For instance, some could be simple calculated – e.g., the use of recycled materials or solar electricity generation as a percentage of the total value – while others might be somehow obtained – computed using a subjective (*acceptability to surrounding community*) or objective yet arbitrary (*affordability* or *desirability*) method; categorized based on a ranking (energy ratings derived from a Building Code or Universal Design Principles), or mutually-exclusive checklist (*Construction Methods* or *Financial Procurements* sources) – yet their validity may be limited and context-specific.

Moreover, there are performance measures that are basically undefined (*subjective size assessment* and *mixed sizes* are not even defined in the paper) or would be complicated to measure (for example, no threshold is provided in the paper to indicate what *low* means in the context of *low VOCs*, nor a suggestion of simple and accessible equipment or procedures to measure VOCs). To be fair, the authors are first to acknowledge the limitations of their framework:

"Generally speaking both the background research into the assessment framework and the discussion forum highlighted the fact that those indicators dealing with environmental sustainability are reasonably well defined (i.e. energy, water, materials and methods). Furthermore, there are tentative levels of performance available for each sub-indicator. This is not the case with the indicators dealing with economic and especially social sustainability (i.e. affordability, dwelling size, density, adaptability, social acceptability and desirability. These indicators require further definition and the methods for measuring performance are in need of considerable research to render the indicators useful when assessing affordable and sustainable housing. Furthermore, the derivation of indicators has highlighted the issue of interdependence and the subjectivity of assessment frameworks in general". Pullen et al (2010)

Additionally, they condense the feedback obtained from the industry discussion forum where their framework was presented:

Indicator	**Possible modification/ further research required**
Energy efficiency	Decouple performance measures for energy efficiency from those regarding energy generation
Construction materials	Performance measures are needed regarding robustness/durability and impact on occupants' health.
Construction methods	The relationship between building regulation and adoption of innovative and non-conventional methods. Need to consider broader governance issues
Affordability	Consider broader performance measures that better reflect locational issues, transportation and land cost.
New aspects	Safety Quality of life Quality of place Health

Figure 11 Pullen et al (2010) Interim Affordability and Sustainability Framework feedback from discussion forum

Still, the framework is relevant to the purpose of this thesis, since it illustrates the efforts required to balance the inputs of diverse stakeholders – construction, architecture and urban & social planning firms, different types of entities within the multiple levels of government and the *consumer* of affordable and sustainable housing – that adhere to either a more theoretical or empirical approach while going beyond easily definable quantitative metrics – mostly the basic environmental ones – provided by Velazquez et al (2022) and into the realms of complex socio-economic metrics.

Moreover, Pullen et al (2010) avoid concluding their framework once it seems debatably complete (as both Chan and Adabre (2019) and Gan et al (2017) do with their CSC and KSPI assessments) but aim to provide working definitions of some metrics – *affordability*, *desirability*, *social acceptability* – and consider external inputs to observe the limitations of their framework and, consequently, propose necessary further improvements.

INFONAVIT's improved assessment of quality affordable housing

As described at length in the Introduction, several efforts were taken by the Mexican federal government to ameliorate the insufficient – and sometimes undesirable – results, of the affordable housing expansion attempt after a decade (2000 – 2010) of increased operations, mainly aiming to improve the quality and sustainability of housing.

A notable effort to enhance the assessment of and comparison between housing units is ECUVE, which "allows INFONAVIT to obtain a qualitative score of the quality and the surroundings of each unit within the housing portfolio based on the attributes obtain from official sources and institutional systems. The purpose of ECUVE is to be an objective measure of borrower's well-being improvement trough the quality of their housing and its environment (…)" INFONAVIT.

The ECUVE, is comprised of three categories: Housing, Environment and Community. The first category performs an assessment of the house *per se*, using four criteria, while the other two are devoted to the infrastructural, environmental, economic and social interfaces of the dwelling and its urban system, using three criteria each, for a total of ten, again – albeit now each criteria has several indicators.

For clarity, a table gathering the ECUVE's criteria and indicators – including points awarded for each fulfilled indicator that enable the dwelling's quality assessment on a 0-180 scale – based on the information published by INFONAVIT[43] (originally in Spanish), is presented as Appendix C.

The ECUVE provides a much more comprehensive perspective on *quality* housing than the deficient and narrow sighted original ten criteria[44]. For starters, it devotes most of its indicators to systemic elements, i.e., the relationship between the dwelling and its urban environment, in terms of both access and availability of services within the house – gas, internet, sewage, etc. – and nearby surroundings, mostly related to public infrastructure – transport, lightning, welfare facilities (education, healthcare, recreation, etc.), among others. Furthermore, it provides quantitative inputs related to disaster resiliency, the relevant gap identified – and previously mentioned – by Charoenkit & Kumar (2014).

Nevertheless, its strengths are a double-edged sword. The assessment increased broadness entails an inherent weakness, namely its dependance of statistical rates published by official sources – collected on a multiyear basis (typically the census performed every decade by INEGI) – which could mean that data is not always available, updated or necessarily representative of the local context. Additionally, a third of indicators devoted to the first category, housing, related to the quality of the house *per se*, are dependent upon the availability of services. Another third of indicators are related to the dwelling size, and the remainder three are related to construction quality and water and energy efficiency.

Finally, no mention of the embodied energy of materials – to measure the intrinsic environmental impact of housing, beyond its operational impact – or associated with the design of housing – such

[43] See INFONAVIT's ECUVE description
[44] Included within Appendix A

as passive design or the inclusion of *eco-tecnologías* (ecotecnologies) – are provided. However, the improvement between the original assessment and ECUVE is like that of day and night.

Chapter 2 – Framing & Enclosure

The establishment of a standard involves exhausting every practical and reasonable possibility, and extracting from them a recognized type conformable to its functions, with a maximum output and a minimum use of means, workmanship, and material, words, forms, colours, sounds (...)
The establishment of a standard is developed by organizing rational elements, following a line of direction equally rational. The form and appearance are in no way preconceived, they are a result (…) *Architecture is governed by standards. Standards are a matter of logic, analysis and precise study. Standards are based on a problem which was been well stated*.
– Le Corbusier (Towards a New Architecture)

As could be appreciated from the literature review, most authors that establish the characteristics that describe desirable affordable housing typically categorize and be present them as a trinity: economic, environmental and social. While there are subtleties related to each, "social sustainability is an open and contested concept" (Bostrom, 2017), since it is both "a dynamic concept, which will change over time (…) in a place" (Dempsey et al, 2011) and due to its dual nature – "(…) including both procedural aspects (…) and substantive aspects, that center on 'what' is to be done (i.e., the social goals of sustainable development). The procedural aspects include the 'how' or the means to achieve these goals" (Bostrom, 2017) – that complicate its measurability, there are some authors that completely renounce the effort to strive for a set of criteria of cohesive, clear, objective and quantitative metrics. This flaw was observed not only within sources discussed in Chapter 1 but also in several documents published by governments or government-backed initiatives.[45]

Moreover, it was impossible to find a framework or set of criteria aiming to assess the *quality* and sustainability of *affordable* housing, that reconciled those properties as a result of its intrinsic form and function, enabling an assessment that could clearly inform a design process.

Therefore, *Table 2* aims to address this gap, and help practitioners in assessing and comparing *affordable*, *quality*, sustainable housing design – before construction – by integrating an eclectic collection of indicators – in systems argot, *figures of merit* – based on sources listed within the Literature Review (complemented by a few Passive House criteria[46] and specific sources discussed in Chapter 3) and guided by the systemic structure (more accurately, its inherent formal decomposition) provided by one of its sources, the "7S Model".

[45] For example, Baukultur and Building for Life.
[46] See Passive House documents

It is important to note that an additional eighth layer was added to the original 7S Model. Paraphrasing Crawley et al (2016), the desirable effects of the expected functionalities will yield benefits greater than those provided by its individual elements – the definition of emergence[47] within a system[48] – which explains the addition of this eighth layer to better reflect the nature of the expected emergence from the whole[49] System (House Boundary) – and the allocation of specific functions to each of the now 8 layers and its *figures of merit*.

But first, to enable an assessment of the emergent properties of a system – a house – and compare the performance[50] of multiple housing designs, the function of the system – and its elements – shall be established. So, the function – to provide shelter – is derived from Le Corbusier's definition: "A house: a shelter against heat, cold, rain, thieves and the inquisitive. A receptacle for light and sun. A certain number of cells appropriated to cooking, work and personal life."

---

[47] "Emergence occurs when the functionality of the system is greater than the sum of the functionalities of the individual entities considered separately."
[48] "A system is a set of entities and their relationships, *whose functionality is greater than the sum of the individual entities*. This emphasized phrase describes what is called *emergence* (…) what appears, materializes, or surfaces when a system operates. Obtaining the desired emergence is why we build systems."
[49] It becomes reasonable to understand that, while the metrics (25-30) of the eighth layer are relevant to some (e.g. disaster resilience) or all elements of the system (safety, cost, etc.), they are more important to the whole – meaning that optimization at only one layer might be irrelevant, since it would be asymmetric. For example, if the cost of the Site (land) is low, but the Structure (skeleton and foundation) is expensive, or if the Stuff (say, appliances) are highly energy efficient yet the Skin's (façade) insulation is poor.
[50] "Performance is how well a system executes its function(s)."

Table 2 Set of criteria to assess affordable housing quality

Layer (7S Model)	Function	Form (7S Model)	Figures of Merit (Multiple Sources)	Units
(Urban) System	Enable access (to nature and urban infrastructure)	The structures and services that facilitate the overall functioning of the system, e.g.: • Roads • Railways • Electricity • Water • Wastewater • Telecommunications • Parks • Schools • Digital infrastructure	1) Access to welfare facilities (Education, healthcare, leisure, supermarket, etc.) 2) Access to green public spaces 3) Commuting cost to work 4) Public transport availability 5) Walkability / Cyclability	1) Distance (m) – ideally ≤500m – and number of facilities 2) Idem 3) Cost (USD and as % of income) & time (hrs) per commute. 4) Number and frequency of public transport routes 5) Availability to walk or cycle to welfare facilities (existence of sidewalks and cycling-suitable roads)
Site	Provide space	The fixed location of the building	6) Land use efficiency 7) Orientation 8) Housing density	6) Usable area (% of space / site) 7) Angle (E-W) 8) Dwellings per hectare (dph)
Skin	Provide shelter Enable breathing (access to natural ventilation) Enable seeing (access to daylight)	The façade and exterior	9) Airtightness 10) Ventilation 11) Insulation 12) Comfort	9) Air permeability per unit length & area (m^3/hm & m^3/hm^2) 10) Estimated air flow (l/s/person) (ideally above 10 l/s per person) 11) According to R-Values and U-Values provided by the ICC[51] 12) Acceptable average indoor temperature (°C)[52]
Structure	Support load	The building's skeleton including the foundation and load-bearing elements	13) Structural capacity 14) Embodied energy of materials 15) Pre-fabrication	13) Weight per surface area (kg/m^2) 14) Emissions (tCO_2e) per unit of weight, volume or energy 15) Prefabricated materials percentage (vs. built on-site)
Services	Enable survival (fulfillment of basic physical human needs: hydration, nourishment,	The pipes, wires, energy, and heating systems	16) Renewable Energy 17) Water Capture	16) Renewable energy (kWh) in % (est. yield / est. use) per year 17) Water capture (m^3) in % (est. yield / est. use) per year

[51] See Appendix D
[52] See Appendix E

	personal hygiene, rest), digital connectivity and access to information		18) Services Availability	18) Availability of services (water, waste collection, gas, electricity, sewage, internet) – Yes/No
Space	Enable health, leisure, rest and movement (indoors)	The solid internal fit-out including walls and floors	19) Dwelling Size 20) Adaptability 21) Accessibility	19) Available area in sqm (ideally $\geq$ 80 m^2 and minimum $\geq$ 60m^2) 20) Incremental potential in % (future expansion / initial area) 21) Rating based on universal design principles[53]
Stuff	Facilitate survival (see Services' function) Reduce environmental footprint	The rest of internal fit-out including the furniture, lightning, and ICT.	22) Energy Efficiency 23) Water Efficiency	22) Based on kWh/year/m^2 23) Based on a m^3/year/m^2
System (House Boundary)	Enable long-term habitability	The whole house	24) Delivery Time 25) Cost (CAPEX) 26) Durability 27) Maintenance Needs 28) Safety 29) Disaster resilience	24) Days until completion 25) USD per unit area (m^2) 26) Est. lifespan (years) before replacement 27) Est. maintenance costs per year (ideally < 2% of CAPEX) 28) According to proposed safety checklist[54] 29) According to proposed disaster resilience checklist[55]

[53] See Appendix F
[54] See Appendix G
[55] See Appendix H

Chapter 3 – Finishes & Inspections

Because definitions are a product of rigid reasoning, quality can never be rigidly defined.

But everyone knows what it is.

– Robert M. Pirsig (Zen and the Art of Motorcycle Maintenance)

Chapter 3 aims to discuss some limitations of *Table 2*. First, it is necessary to say that *Table 2* does not intend to be a universal or standard framework (alas, it does not even claim to be a framework since that would constrain the dynamic natura of the applicable context!) nor to state the obvious, by reminding the reader the basic function(s)[56] and form[57](s) of a house and its elements (doing so, is only part of applying system thinking[58] to housing – ideally, *affordable* housing, although the criteria would be applicable to housing in general and, perhaps, other types of construction).

Second, there are at least two common limitations for all criteria. One, stems from the act of grouping arbitrarily some criteria into what could be interpreted as a standard that disregards its application context – some authors plausibly suggest that, in analyzing the interfaces between the environmental, economic, and social sustainability aspects "a single framework (…) is neither feasible nor desirable" while emphasizing the "need to contextualize the analysis" (Eriksson, 2016) – while the other (and arguably the most important one) is the lack of discussion regarding the existing trade-offs and interrelationship between the *figures of metric* – stemming from different housing design decisions (for example, between comfort and energy efficiency) – which could be informative for *stakeholders* related to affordable housing programs.

Additionally, several proposed criteria and its *figures of merit*, have specific limitations that are grouped and described below, under a subtitle that relates to the inherent limitation stemming from its type of criteria.

All quotes in this footnote are derived from the book "System Architecture" by Crawley et al (2016):

[56] "Function is what a system does; its activities, operations and transformations that cause, create, or contribute to performance. Function is the action for which a thing exists or is employed. Function is not form, but function requires an instrument of form. *Emergence* occurs in the functional domain."

[57] "Form is the thing that is built; the creator of the system builds, writes, paints, composes, or manufactures it. Form is not function, but form is necessary to deliver function."

[58] "System thinking is, quite simply, thinking about a question, circumstance, or problem explicitly as a system – a set of interrelated entities (…) System thinking can be used in a number of ways: to understand the behavior or performance of an existing system; to imagine what might be if a system were to be changed; to inform decisions or judgements that are of a system nature; and to support the design and synthesis of a system, which we call system architecture."

Ballpark Criteria

Generalizing a single deterministic value for these criteria is rather undesirable, since the criteria is somewhat background-specific, thus variable, although, providing a ballpark – an average or minimum value or even a desirable threshold – is useful.

Public Transport Availability – An ideal distance (≤ 500m) to access public transport (bus, tram train stops) is indicated by Epimakhova, 2016. Complementing it with an estimated desirable frequency and coverage (percentage of access to the urban footprint) of service would be ideal, although harder to measure[59].

Maintenance Needs – Although standardizing a list of activities, and their estimated frequency, to maintain the house *quality* during its lifespan could be thorny, an attempt is done by Kim et al (2018)[60]. Another effort performed by Lee et al (2014) aims to estimate the "repair cycle of the components of the apartment housing".

Nevertheless, we adopt a *figure of merit* that encompasses maintenance needs within a yearly cost estimate – provided by Harding et al (2007), who performed a roughly two decades (1983-2001) analysis of housing data collected by the American Housing Survey, providing several figures related to the "Depreciation of housing capital, maintenance, and house price inflation" – that sets "annual maintenance expenditures at 1.38 percent of the purchase price, while the median is 0.64 percent". Although costs for affordable housing could be lower, considering that for the 25th percentile indicated in the analysis, the mean was less than a twentieth of the mean value.

[59] See Rosenbloom, 2009 & Orpana, 2016.
[60] Based on Sout Korean apartment housing

Dwelling Size – As can be seen in the graph below[61], displaying the average size of dwellings in the EU[62], the lower limit is, by and large, 60m^2 (with the evident exception of Romania), whereas 80m^2 constitutes a more representative base value – at least considering most westernmost countries within the EU.

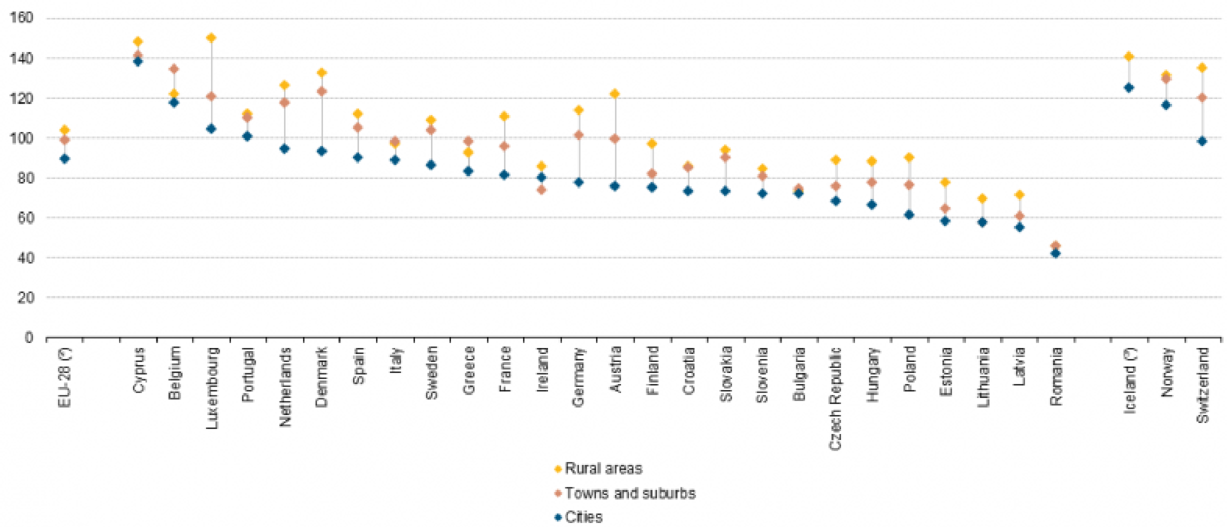

Figure 12 EU average size of dwellings, by degree of urbanisation (2012)

Additionally, the UK's Housing Quality Indicators (2007)[63], provides – among several useful and interesting contributions – a structured guide to assess and compare the *Unit Size* and *Unit Layout* – arguably stemming from a minimum standard for mobility within the dwelling.

Foothold Criteria

Calculating realistic values and even structuring the process to do so, can be cumbersome for these criteria. Therefore, an existing framework to do so is provided, which can be adapted to the applicable context (for example, embodied emissions would be dependent upon a country's power matrix, yet the process to calculate them could be replicated, say from the UK to Mexico).

[61] See reproduced image from Eurostat
[62] See Eurostat article
[63] Version 4 (For NAHP 08-11). Published by the UK's Homes and Communities Agency (now Homes England) in May 2007 (updated in April 2008 and withdrawn in March 2023).

Embodied Carbon – To thoroughly assess the embodied emissions related to the manufacturing of raw materials necessary for housing construction, a proper LCA would need to be performed. Evidently, the same problem that arises when deferring to "building code compliance", applies when considering an LCA (or any analysis that claims *cradle to grave* validity). I.e., data quality and reliability. If that is the case, Monahan and Powell (2011) provide an estimation of embodied carbon of construction materials, using data from the UK which can be extrapolated to other contexts, or used as a point of reference, to be contrasted with other data inputs.

Energy Consumption – Predicting energy consumption – based on several variable factors, including weather conditions and the performance of building systems and materials – is described by Zhao and Magoulès (2012), who explore methods, and its complexities, to approximate it.

A simpler yet objective mechanism may be found within the denominated *Whole of Home* assessments and ratings, published by Australia's NatHERS, as part of the Australian Government "*Trajectory for Low Energy Buildings*[64]". Complementarily, Ren et al (2023) provide a case study and discuss the application of a tool developed by Australia's CSIRO (based on the *Whole of Home* rating), to better understand – with the aim of further improving – existing housing in Australia, that can be applied – with context-based adaptations, such as climate conditions including average outdoor temperatures – to housing projects within other countries.
Similarly, Moghayedi et al (2023), provide a reference of energy consumption for affordable housing, based on the SIAH-Livable project in South Africa.

Checklist Criteria

Providing a rigorous, unquestioningly valid definition for these criteria is impossible.

[64] Described as "a national plan that aims to achieve zero energy (and carbon) ready commercial and residential buildings in Australia" within NatHERS website. See https://www.nathers.gov.au/resources/faqs.

Nevertheless, a collectively exhaustive list of requirements can become, in sum, an applicable approximation. Typically, these list stems from a *via negativa*[65] approach to empiric observation (for example, the original ten criteria of *substandard* housing in Mexico, define *quality* housing implicitly, i.e., only as the opposite of one with insufficient characteristics).

Safety – Defining (and even worse, intending to measure) safety in housing using quantitative terms is challenging[66] (sometimes outright infeasible, unrealistic or unnecessary) since it intertwines several aspects of living – enabled by all system layers (from site to stuff), although it should be addressed at the system level, as Nancy Leveson would suggest[67] – including both individual (physical, mental, emotional) and social aspects.

Although ranges, thresholds, or scales can be established for a more precise assessment – for example, Pihelo et al (2020) provide a *Mold Index*, based on a 6-tier description of *Mold Growth* resulting from undesirable levels of moisture content of different common building materials (including wood, concrete, etc.) – it is easier and more robust to do so *via negativa*, by defining and removing undesirable sources of poor safety (from illness and discomfort to serious injury and death) – thus preventing its effects. Therefore, two comprehensive list of hazards – provided by Keall et al (2010) and Nix et al (2020) – are considered to be a good approximation to aim for system-level safety.

---

[65] As Nassim Nicholas Taleb describes in Antifragile (2012): "*Via negativa* does not try to express what God is –leave that to the primitive brand of contemporary thinkers and philosophasters with scientistic tendencies. It just lists what God is not and proceeds by the process of elimination. (…) In practice it is the negative that's used by the pros, those selected by evolution: chess grandmasters usually win by not losing; people become rich by not going bust (particularly when others do); religions are mostly about interdicts; the learning of life is about what to avoid. You reduce most of your personal risks of accident thanks to a small number of measures."

[66] The US HUD Inspection Checklist (OMB Approval No. 2577-0169, Exp. 04/30/2026) basically addresses only: the presence of lead-based paint (*exceed two square feet per room and/or is more than 10% of a component?*), electrical hazards, smoke detectors; "security"; the "condition" of windows, ceilings, walls, floors; and "other potentially hazardous features".

[67] Multiple quotes from Nancy Leveson (2012) book: *Engineering a Safer World: Systems Thinking Applied to Safety* relate to this point. For example: "Making all the components highly reliable will not necessarily make the system safe" and "Safety is a system property, not a component property, and must be controlled at the system level, not the component level."

Disaster Resilience – Following the same approach to approximate safety, McConkey & Larson (2022) provide a broad assessment of variables related to disaster resilience[68], grouped in 5 categories: Social, Economic, Institutional, Infrastructure, Community, applying the *Baseline Resilience Indicator for Communities* (BRIC), "(…) an index based on variables representing resilience attributes identified in the literature". While it might indeed be a comprehensive assessment to enable community resilience, few variables are relevant to housing design[69]. Similarly, the UNDP collects a list of hazards[70] – natural, human-made & technological and security risks – that are collectively exhaustive yet include little guidance on their applicability.

In contrast, the US HUD *Community Resilience Toolkit* (2023)[71] is a more applicable guideline to prepare for and act upon climate-related natural hazards (drought, erosion, extreme heat, inland flooding, wildfire, etc.) that may impact housing, providing a specific vision[72] and criteria to enable disaster resiliency.

When prioritizing disaster resilience, it is necessary to consider the likelihood of climate-related events based on the local context. While assessment tools based on historic data is never an infallible source to predict the future, it might be a useful reference, that can be paired with real-time data published from publicly available monitoring tools[73].

---

[68] Similarly, the OECD prepared a working paper to increase systems resilience and guidelines to "analyse risk and build a roadmap to resilience"
[69] A common problem, considering several documents about or related to disaster resilience in housing, are insufficiently pragmatic to become directly applicable, becoming instead a programmatic instrument to be read by bureaucrats or office administrators. For example, FEMA's Planning Considerations: Disaster Housing,
[70] See page 23 of the "Guidance notes on building critical infrastructure resilience in Europe and Central Asia".
[71] See Toolkit
[72] See Appendix H
[73] Regarding Mexico's context, Sánchez-Partida et al (2021) book on *Disaster Risk Reduction in Mexico* is an example of the former, and CONAPRED's *Atlas Nacional de Riesgos* (National Risks Atlas), of the latter.

Absent Criteria

While preparing a set of criteria that covers all minutiae related to housing is beyond the purpose of this thesis, it is imperative to acknowledge – chiefly to encourage further efforts of improvement – the absence of several criteria related to housing, without which we have, at best, an approximation to *quality*. Virtually, all have been omitted since they are not strictly dependent upon housing design – thus can still be influenced after construction (e.g., indoor air quality or material reuse) – while others are abstract and would require the development of further frameworks or consensus about its potential implementation.

Health – Including a thorough list of criteria related to human health and its relationship to the housing is, arguably, the major omission of Table 2. Clearly, the availability of services that facilitate living conditions necessary for people to survive and thrive – namely water, electricity, gas, etc. – along with specific criteria aimed at measuring the extent to which the house enables the relationship between its inhabitants and its surroundings – air flow, daylight, etc. – is included. Nevertheless, its needed complement – a desirable threshold or minimum value – regarding the *quality* of the input (*operand*[74] in system architecture argot) that is enabled by the services or the housing design, should be added. For example, *figures of merit* related to indoor air quality, water purity, light intensity (illuminance) and (tolerable) noise pollution.

Circularity – Specific criteria and *figures of merit* related to the circularity of elements – based on the ReSOLVE framework – could be added. For example, the potential to reuse, remanufacture, and recycle – *Optimize* and *Loop* – construction materials necessary to build the Structure and Skin of the house, and the need to consider the relationship between the house (and its inhabitants) with their immediate community – reuse Stuff or *Share* – and trade goods and services – *Exchange*.

[74] "Function consists of a *process* and an *operand*. The *process* is the part of function that is pure action or transformation (…) The *operand* is the thing whose state is changed by that process. Function is inherently transient; it involves change in the state of the operand (creation, destruction, or alteration of some aspect of status of the operand)." Crawley et al (2016).

Earning capacity – Useful criteria and *figures of merit* that assess access to economic opportunities – i.e., the potential to join the formal labor market, perform entrepreneurial activities, or procure self-sustenance from natural resources (farming, fishing, etc.) or any other means of legal income-generation – available would be fundamental to both understand the affordability of the house for its inhabitants – using income-related benchmarks – and their potential to thrive.

Customization – Mohamed & Carbone (2022) remind us that for decades "designers sought to combine the advantages of mass production with architecture's need for singularity and uniqueness". Thus, there is potential in finding the balance between both, by enabling the mass customization of housing. These authors provide the case – interestingly, citing work performed at MIT[75] – for increasing flexibility through the combination of a framework to think about this systemic approach and multiple technologies to implement it.

[75] "The work by *House_n*, a former digital media and housing research group at MIT's Department of Architecture defined three necessary elements for the mass customization of housing. First, a *preference engine* for customer profiling. Second, a *design engine* that employs computational set of rules encoded into a shape grammar to generate design solutions in response to the profiling process. Finally, a *production system* that relies on digitally controlled machines for construction." Mohamed & Carbone (2022)

Chapter 4 – Final Touch & Move-in

The fool generalizes the particular; the nerd particularizes the general; some do both; and the wise does neither.

– Nassim Nicholas Taleb

Final thoughts

It is important to note that this thesis – and perhaps any work that aims to provide a quantitative framework to address a complex system dealing with human nature and its socio-technical implications – is limited in its output, for several reasons.

One reason is the semantic depth of the terms necessary to define the system boundary and categorize its characteristics. First, the terms housing unit, dwelling, and similar synonyms have been so far used almost interchangeably as synonyms. Nevertheless, multiple texts within academic literature suggest that these terms are nuanced, such as:

"Anthropological approaches have recently begun to develop and elaborate a distinction between the house and the home, wherein houses involve normative, widely reproduced, and often material forms, while homes centre around the subjective feelings of belonging and dwelling." Samanani and Lenhard (2019).

Others go further, pleading us "to be cognisant of ontology and language" (Ellsworth-Krebs 2014), while sharing the implications of choosing one term over another. Furthermore, other research reminds us that these terms entail different meanings and profoundness, which may be useful to understand specific characteristics:

"(…) home is a multidimensional phenomenon, neither unidimensional nor created from a set of standard qualities pertaining either to the person or place. Rather, each home features a unique and dynamic combination of personal, social and physical properties and meanings. This provides one explanation for the wide range of different types of home and tends to support the finding that the sort of place that is home for one person is not necessarily home for another. However, going beyond personal notions of home, a general, somewhat tentative model of home experience provides a base within which personal meanings of home can be psychologically located." Sixsmith (1986).

Thus, the reader will appreciate that the system emergence – and its enabling functionalities – are related only to the notion of house, since expecting to be able to yield the notions of a home through following a set of criteria, would be naïve. Nevertheless, there is value to be derived from understanding and discussing the function of a house, even if the used function definition is inherently limited.

Along this thesis, a few extracts of Le Corbusier's *Towards a New Architecture* (1986)[76] may have allowed the reader to grasp his philosophy of architecture – which would be supplemented by several other books later published – mainly sustained by the overarching idea of why and how modernity should transform it.

While arguing for or against Le Corbusier's ideas in general or specifically is beyond the purpose of this thesis, it is necessary to recognize his influence in addressing the role that *functionality* should be given by the architect, behind his idea of a house as *a machine to live in*.

Although Le Corbusier might not have been the original proponent of the importance of function in architecture – Stoneham and Smith (2015) recall that in 1896 Louis Sullivan "developed the mantra *form follows function*" – or even its most famous advocate – also Stoneham and Smith (2015) recall that it was Frank Lloyd Wright who "(…) developed his alternative, '*form and function are one'* (…) creating an equilibrium between the natural world and the built form" – he undoubtedly became a leading advocate of thinking about standardization as a solution to functionality and the necessity of mass-production to satisfy the needs of a growing population.

[76] See the book

Indeed, some authors – such as King (2008) – rightfully criticize the limits of standardization – and its inherent opposition to universal design and the need to account for individual needs and inclusivity – and some of its devastating effects when controversial ideas are disguised under its notion of modernity – as recalled by Lopez-Duran (2018) – while others are able to refrain from those discussions and limit themselves to recognize its intrinsic utility: "the establishment of standard becomes necessary, not in generating standard architectural forms but in defining the performance standard of architecture for human well-being" Atmodiwirjo & Yatmo (2015), which becomes necessary when aiming to evaluate whether a complex system is fulfilling its purpose.

Conclusion

As conveyed above, writing this thesis became first and foremost an exercise in humility, since it unearthed several reflections about…

a) the puzzling complexity of trying to find or create a descriptive set of criteria of what affordable *quality* housing *is*, including philosophical, architectural, socio-technical considerations.
b) the existing trade-offs between pragmatism and comprehensiveness, standardization and accessibility, feasibility and scalability, and many others when thinking about the possibility to transform and improve the status quo.
c) the lack of easily accessible tools for non-practitioners that enable cross-functional design including architecture, engineering, interior design and comparison between multiple concepts.

Nevertheless, this thesis helped me strengthen the importance of system thinking when dealing in complex problems and the need for multidisciplinary approaches – perhaps, what Isaiah Berlin would call, choosing to become a fox rather than a hedgehog.

Appendix A

Source: CIDOC (2004)

Tabla C-1 Participación de viviendas de mala calidad

Categoría	Característica	1990	2000
Materiales	Pisos	19	19
	Muros	29	32
	Techo	47	39
Espacio	Cocina	20	23
	Baño	23	15
	Hacinado	48	41
Servicios	Electricidad	12	8
	Agua	49	49
	Drenaje	37	37
	Cocinar	21	29

Fuentes: JCHS 1997; cálculos de JCHS, datos del INEGI 2000

Figure 13 Survey results of substandard housing

Appendix B

Source: Charoenkit & Kumar (2014)

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
1 Site plan to reduce UHI					
1.1 Orientation	A study of microclimate	% of buildings with proper orientation (75%)	Form of building groups	The angle of building axis to E–W (5–30°)	Cross ventilation throughout the project (simulation)
			Measures to cope with strong wind Amount of sunlight exposed to public spaces	% of buildings in adjacent site that will be shaded (35–0%)	
1.2 Shaded area		% of shaded area by trees or structure (40%) or % of streets with trees (60%)	% of horizontal shade area % of green space	% of area shaded by tree (50–100%) LAI (0.3–1)	% of shaded pavement (50%) % of tree covers (20%)
1.3 Outdoor surface		% of roof with SRI > 29 (75%) or	% of paved area	% of landscaped area and high reflective surface (50–100%)	% of hardscape with SRI > 29 (50%)
		% of non-roof with SRI > 29 (50%)	Presence of green roof % of green wall % of reflective wall Ratio of building height to site width to avoid wind blockage Spacing between building Continuous open space		
2 Building energy use					
2.1 Building envelope	Use of best practice standards in sustainable design Rating level of certified buildings Presence of energy strategy to reduce carbon emissions	% of certified building	% of energy demand reduction (5%, 10%)	Predicted differential wind pressure in pascals (15–45 Pa) Air change rate during summer (0.5–1.0 ach) Air change rate during spring (0.8–1.5 ach) Air change rate during winter (0.4–0.8 ach) Air movement in conditioned area (0.2–0.8 m/s) % or air reaching work surface in conditioned area (30–50%) Compliance of mechanical system design to ASHRAE standard 55-1992	% of certified building
2.2 Renewable energy		% of onsite renewable energy generation (5–20%)	Use of renewable energy technologies (< 10%, > 10%)	Degree of structural adaptability for installing solar PV system	% of onsite energy generation (5–10%) % of renewable energy supply (5–20%)
2.3 Efficient energy use	Compliance with local lighting design % of street lighting efficiency	% of energy saving from street lighting (15%)		% of light lumen in an upward direction (2.5%) and the provision of automated daylight sensor controls Daylight factor of living area at ground floor (0.02–0.04 DF) Illumination level of 30–500 lux and the area interval provided with dimmable ballasts (15–10 m^2) Size of lighting system control zone (50–25 m^2) Separated thermostat for different functions	Compliance with local standards
2.4 Low carbon materials	Use of reused or recycled buildings/infrastructure/ materials	% of recycled content in infrastructure (50%)	Use of recycled concrete (partial, full)	% of building reused (10–30%)	% of recycled content in infrastructure (10%)
	% of low impact materials used		Use of low carbon products (partial, full)	Weight of building materials per area (2500–1000 kg/m^3)	% of recycled content in building structure (10%)
			Use of certified timber (partial, full)	% of non-renewable materials (80–30%)	% of regional materials manufactured

Figure 14 Charoenkit & Kumar (2014) GER and DRL indicators of five tools

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
					within 0.5 km (70%)
				% of exposed floor, wall, ceiling (10–30%)	
3 Waste management					
3.1 Modular design		Consideration for reducing construction wastes during design and construction stages (partial, full)			
3.2 Construction waste	Waste management plan		Presence of waste management activities e.g. sorting, recycling, reuse (partial, full)	Plan, center, disposal site	
	% of wastes diverted from landfill				
3.3 Solid waste		Presence of station, drop-off point	Presence of waste facilities	Provision of sorting facilities	Presence of station, drop-off point
			Category of waste sorted	No. of units with storage of solid waste and recycling (75–95%) Amount of liquid waste sent off from the site per year (0.35–0 m^3/pp)	
4 Land use efficiency					
4.1 Previously used land	Use of previously developed land (75%)	% of the development on developed/infilled site (75%)			Location on developed site
4.2 Housing density		Number of units/acre		% of floor area complied with the standard (50–100%) No of land use (1 ≥ 3) Ratio of net functional area to occupied area (85–95%) Ratio of functional volume to occupied volume (85–95%)	% of density above standard
4.3 Open space			% of open space	Provision of open space (sufficient, convenient, comfortable)	% of open spaces (15%)
					% of green space (+25% above standard)
5 Transport planning					
5.1 Walkability	Presence of transport assessment	Continuous sidewalks	Presence of cross circulation between vehicle and pedestrians	Quality of bike and walkway (bikelane, interval of connection with off-site bike path , shelter, distance to main building)	Pedestrian network that is linked from hubs/ shaded/safe
	Measures taken to create safe and appealing streets/ walkways Design criteria for cycling network Provision of cycling storage	Bicycle network and storage		Quality of walkway (% of access_ 10–20%, % of sheltered_25–50%)	Provision of cycling network+storage
5.2 Access to facilities	No. of facilities located within walking distance (650 m for urban/1300 m for rural)	Distance to parks (400 m)	Distance to supermarket (300–1500 m)		Existence of utility systems without extension
	Provision of utility services e.g., gas, electricity, water, telecommunication	Distance to recreation facilities (400 m)	Distance to bank		Distance to amenities (500 m)
	Distance to green space	Distance to school (1600 m) for 30% of units	Distance to local government's office		Number of jobs/ schools/amenities within 500 m
			Distance to hospital Distance to welfare facilities Distance to schools Distance to cultural facility		
5.3 Access to public transport	Distance to transport node	Frequency of transport trips			Frequency of transport trips
	Provision of transport facilities	Presence of transit station			Presence of transit station/walkway

Figure 15 Charoenkit & Kumar (2014) GER and DRL indicators of five tools (continued)

TOOL	BREEAM	LEED	CASBEE	SBTool	GBI
6 Water management					
6.1 Efficient use	Presence of water strategy	Use of efficient fixtures % of water saving (> 40%)		% of landscaped area with native species (50–100%) Amount of irrigation water (0.2–0.05 m^3 m^2/year) Amount of water consumption (0.05–0.01 m^3 m^2/year)	% of water saving (5–20%)
6.2 Reused water	*Included in the indicator of adapting to climate change	% of water saving for landscaping (> 50%) % of wastewater reused (25–50%)	Presence of water reuse system	% of units using gray water (25–100%)	% of wastewater reused (10–50%)
6.3 Rainwater harvest	*Included in the indicator of Adapting to climate change		Presence of rainwater storage (central/individual)		
6.4 Permeable surface	Peak rate of surface run-off	% of retaining stormwater on-site (80–95%)	% of area undertaken measures to reduce runoff (50%, > 50%)	The ability of stormwater system to cope with 100 year flood events	% of decreased runoff (25%)
	% of hard surface designed for rainwater harvesting (> 5%)	% of permeable surface (5 ≥ 15%)	% of stormwater treated by onsite system (25–100%) Amount of retained water (standard or 300 m^3/ha)		
7 Disaster planning					
7.1 Risk zone	Flood risk assessment	Development on no/low risk zones or moderate zones with the compliance with local standards		Development on no/low risk zones or moderate zones with the compliance with local standards	
7.2 Building resilient design	Minimum floor level (0.60 m)/Under Adapting to climate change	Compliance with local standards			Compliance with local standards
7.3 Utility planning	Avoidance of risky area		Compliance of the design for water supply and treatment system with local standards Provision of common water supply for emergency Provision of common facilities for storing sewerage Provision of backup system		
7.4 Evacuation planning			Size of open space used as shelter Road width (8 m) and the number of exit (2) Distance to evacuation area		
7.5 Local food	Area for community garden/ unit (5–20 m^2/unit)	Area for community garden/unit (5–20 m^2/unit)			
8 Community participation	Consideration of demographic needs and priorities Consultation plan with stakeholders/workshop organization A panel set up to undertake a design review	Community meeting Community workshop	Participation in planning processes (no/some stages/ all stages)		Address issues of existing communities Presence of community center
9 Economic consideration				Construction cost/m^2 (2000–1500 EUR) Operating cost/m^2 (200–100 EUR) Life cycle cost/m^2 (3000–2000 EUR)	

Note: Indicative values are indicated in bracket ( ).

Figure 16 Charoenkit & Kumar (2014) GER and DRL indicators of five tools (continued)

Appendix C

Source: INFONAVIT

Table 3 INFONAVIT's ECUVE

Category	Criteria	Indicator	Points awarded
01 Dwelling	0101 Dwelling Quality	Quality insurance certificate provided • 10 years – structural safety • 5 years – rooftop waterproofing • 2 years – installation	100 – Yes 0 – No
		Available natural gas connection within dwelling	100 – Yes 0 – No
		Available telephone line connection within dwelling	100 – Yes 0 – No
	0102 Digital Connectivity	Available internet connection	100 – Yes, if: Wireless/landline internet available and service has been both requested and installed (by provider) 0 – No
	0103 Space sufficiency	Vertical construction	100 – Yes 80 – No
		Average living space	% total built area (sqm) divided by number of rooms – or zero if minimum requirements (38 sqm and 2 rooms) are not fulfilled
		Temporary behavior of living space	Standard deviation of moving average of built area (sqm), based on four-tier percentiles ranking
	0104 Sustainability and efficiency	Water conservation (based on simulation) Energy efficient design	100% "índice de desempeño global de la Vivienda"
02 Environment	0201 Urban Amenities	• Rate of available "green" areas • Rate of government offices, social assistance services, and education services	Data provided by INEGI's DENUE, presented on a "per 100,000 people" basis
		Proximity to welfare facilities • Education: Elementary, Middle and High School • Parks • Healthcare • Public markets	Data provided by INEGI's DENUE
	0202 Municipal Services	Availability of services: • Natural gas network • Telephone landlines • Electrical infrastructure • Public safety • Sewage	Based on a binary (100 or 0, available or not available) criteria, with a third option in between (50) for alternatives where service is available but not as desirable (for example, in public safety, a 100 is provided if municipality provides the public service, but 50 in case it is "autonomous" – likely private for housing development / gated community only)

		• Waste collection & management • Public lightning • Financial flexibility	
	0203 Roads and public transportation	Distance to nearest public transit stop and frequency of service	Data source not provided
		Transport safety (public transit and motorcar crime rate)	Crime rate per 100,000 people (data provided by INEGI)
		Urban Reference (i.e., related to desirability of location, in terms of "centricity" within urban area	Based on a four-tier ranking: 100 – Centric 75 – Intermediate 50 – Peripheric 0 – Rural area (or unclassified)
		Availability of urban signage and nomenclature	100 – Yes 0 – No
		Sidewalk and roadways construction materials	Based on a multiple-tier rankings Sidewalks: 100 – Concrete 50 – Paver 20 – Cobblestone 0 – Other (or unclassified) Roadways: 100 – Permeable material 80 – Asphalt 60 – Concrete 40 – Cobblestone 20 – Paver 10 – Dirt road 0 – Other (or unclassified)
03 Community	0301 Enjoyment of public spaces	Availability of Social Assistance Services	Data provided by INEGI's DENUE
		Availability of public and cultural venues	Data provided by INEGI's DENUE
		Distance to sports facilities	Distance (km)
		Distance to nearest community center	Distance (km)
		Delinquency rate	Data provided by SESNSP. Rate per 100,000 people.
		Homicide rate	Idem
		Diversity and district segregation	Variability of type of dwelling frequency
	0302 Community Resilience	Types of climate disasters and risk level	Type of risk (Volcanic activity, cyclone, extreme temperature, etc.) and risk level (based on a five-tier ranking)
		Frequency of disasters	Data provided by CENAPRED based on the number of Emergency Declarations between 2000 and 2016 per type of risk.
	0303	Labor rate	Data source not provided
		Business presence	Data source not provided

Appendix D

Source: International Energy Conservation Code (IECC) 2018

TABLE R402.1.2 INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION U-FACTOR[b]	SKYLIGHT[b] U-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	MASS WALL R-VALUE[i]	FLOOR R-VALUE	BASEMENT[c] WALL R-VALUE	SLAB[d] R-VALUE & DEPTH
1	NR	0.75	0.25	30	13	3/4	13	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0
3	0.32	0.55	0.25	38	20 or 13+5[h]	8/13	19	5/13[f]	0
4 except Marine	0.32	0.55	0.40	49	20 or 13+5[h]	8/13	19	10/13	10, 2 ft
5 and Marine 4	0.30	0.55	NR	49	20 or 13+5[h]	13/17	30[g]	15/19	10, 2 ft
6	0.30	0.55	NR	49	20+5[h] or 13+10[h]	15/20	30[g]	15/19	10, 4 ft
7 and 8	0.30	0.55	NR	49	20+5[h] or 13+10[h]	19/21	38[g]	15/19	10, 4 ft

Appendix E

Source: ANSI/ASHRAE Standard 55-2017

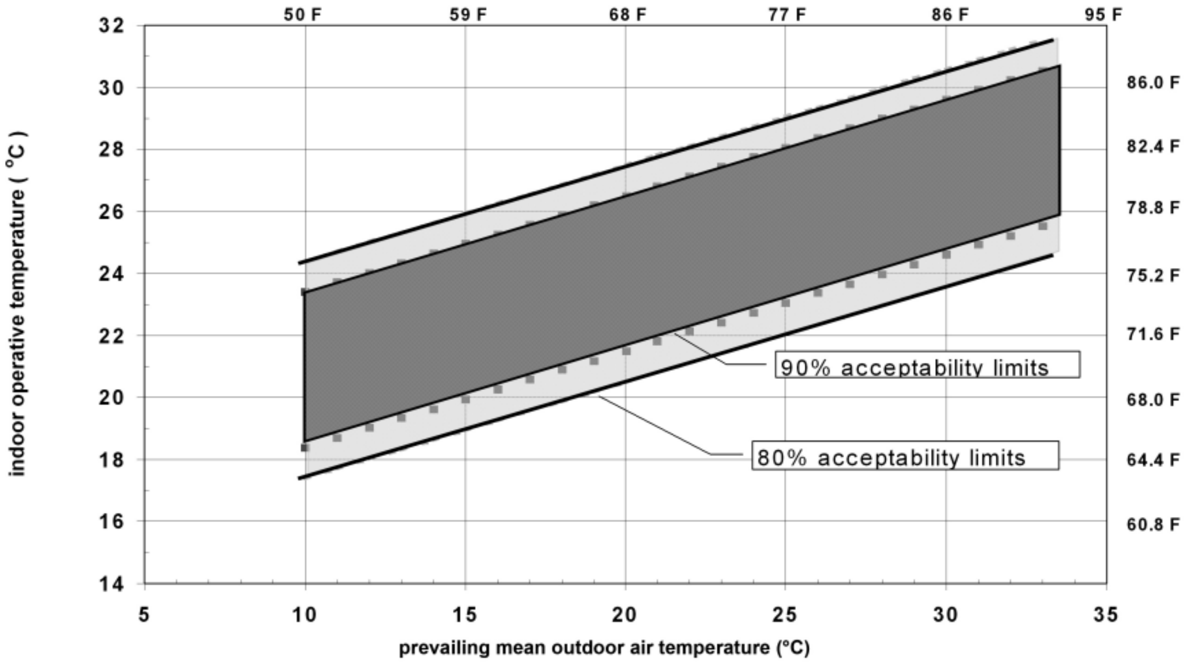

Figure 17 AHSRAE's indoor temperature acceptability

Appendix F

Source: Connell et al (1997), reproduced by Anacker et al (2018)

Principle 1: Equitable Use	
Definition:	The design is useful and marketable to people with diverse abilities.
Guidelines:	1a. Provide the same means of use for all users: identical whenever possible; equivalent when not. 1b. Avoid segregating or stigmatizing any users. 1c. Provisions for privacy, security, and safety should be equally available to all users. 1d. Make the design appealing to all users.
Principle 2: Flexibility in Use	
Definition:	The design accommodates a wide range of individual preferences and abilities.
Guidelines:	2a. Provide choice in method of use. 2b. Accommodate right- or left-handed access and use. 2c. Facilitate the user's accuracy and precision. 2d. Provide adaptability to the user's pace.
Principle 3: Simple and Intuitive Use	
Definition:	The use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
Guidelines:	3a. Eliminate unnecessary complexity. 3b. Be consistent with user expectations and intuition. 3c. Accommodate a wide range of literacy and language skills. 3d. Arrange information consistent with its importance. 3e. Provide effective prompting and feedback during and after task completion.
Principle 4: Perceptible Information	
Definition:	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
Guidelines:	4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information. 4b. Maximize "legibility" of essential information. 4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions). 4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.
Principle 5: Tolerance for Error	
Definition:	The design minimizes hazards and the adverse consequences of accidental or unintended actions.
Guidelines:	5a. Arrange elements to minimize hazards and errors: most-used elements, most accessible; hazardous elements eliminated, isolated, or shielded. 5b. Provide warnings of hazards and errors. 5c. Provide fail-safe features. 5d. Discourage unconscious action in tasks that require vigilance.
Principle 6: Low Physical Effort	
Definition:	The design can be used efficiently and comfortably and with a minimum of fatigue.
Guidelines:	6a. Allow user to maintain a neutral body position. 6b. Use reasonable operating forces. 6c. Minimize repetitive actions. 6d. Minimize sustained physical effort.
Principle 7: Size and Space for Approach and Use	
Definition:	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.
Guidelines:	7a. Provide a clear line of sight to important elements for any seated or standing user. 7b. Make reach to all components comfortable for any seated or standing user. 7c. Accommodate variations in hand and grip size. 7d. Provide adequate space for the use of assistive devices or personal assistance.

Figure 18 Connell et al (1997) Universal Design Principles

Source: Anacker et al (2018)– Chapter 6 (pag. 98-117) by Hartje et al.

Principle 1: Equitable Use

- Multiple-height countertops
- Cutting boards
- Wider interior doorways
- Side-by-side refrigerator

Principle 2: Flexibility in Use

- Full-extension pull-out pantries and drawers
- Railings on both sides of the stairs
- Curbless shower, adjustable-height movable hand-held showerhead or a 60–72 in. flexible hose that allows easy use by people of varying heights
- 48 in. work aisles
- Multiple counter heights
- D-shaped pulls
- Rocker light switches

Principle 3: Simple and Intuitive Use

- Step-less entrance
- Offset water controls in the shower and tub allow for easy access from outside the tub/shower, which reduces reaching and bending, without inconvenience when inside the tub
- Single-lever faucets

Principle 4: Perceptible Information

- Large dial on a thermostat or telephone
- Use of color contrast (for example, between countertop and floor or between sink and countertop)

Principle 5: Tolerance for Error

- Crank- or power-operated counter system or lever handles that can be texturized to communicate to those with low vision that the door should not be opened
- Magnetic induction cooktop that is not hot to the touch

Principle 6: Low Physical Effort

- Lever door handles or loop handle pulls on drawers and cabinets that make it easier to operate with the elbow or the knee when one's hands are full
- Light switches at 44–48 in. high and thermostats 48 in. above the floor, which makes them easier to operate with one's elbow when one's hands are full
- Electrical outlets placed at 18 in. minimum height so they are easy to reach without bending or from a seated position
- Removable cabinet fronts at sink with insulated pipes that improve access to these areas and protect legs from hot pipes
- Varied-height counters that reduce bending and back strain
- Front-loading washer and dryer with front controls that reduce the need to bend, stoop, or lean over to reach clothes
- D-shaped pulls on cabinets

Principle 7: Space and Size for Approach

- Entry doors of 36 in. minimum width, interior doors with 32 in. clearance, and hallway widths of a minimum 42 in.
- Knee space under sinks

Figure 19 Anacker et al (2018) Universal Design Principles applied to housing

Appendix G

Source: Keall et al (2010)

Housing quality feature measured	Hazards associated with housing	Method of measurement	Health, safety and sustainability outcomes
Adequate structural soundness: Adequate foundations Adequate walls, floors Adequate roof, cladding Adequate windows Adequate stairs Adequate chimneys Adequate internal walls Cylinders and header tanks have earthquake restraints	Structural collapse and falling elements†	Visual inspection by trained assessor Measurement of key dimensions (some structural elements)	Injury following natural disaster
Adequate water supply: Adequate potable water Adequate water for non-potable uses	Inadequate or contaminated water supply	Visual inspection by trained assessor Source of water Treatment method of water, if not reticulated	Enteric infections
Adequate sanitary areas and waste disposal: Sanitary and functional toilet Adequate personal washing facilities and hot water Sanitary and functional facilities for clothes washing. Adequate solid waste storage and collection Safe and functional sewage disposal Safe and function storm water, surface water and ground water disposal	Infection from poor hand-washing and sewage Infection from pests (rodents, flies, etc)	Visual inspection by trained assessor including subfloor inspection Test water temperature at hot tap Evidence of pests	Enteric infections
Adequate food preparation areas: Safe and functional cooking device Adequate space/area for food preparation and cleaning, hot water Adequate safe space for food storage	Infection from contaminated food	Visual inspection by trained assessor Test water temperature at hot tap Type and safety of cooking device Surface area and quality of food preparation area	Enteric infections
Adequate safety from falls and other injuries: Safe bath and shower areas Safe decks, surfaces, barriers Safe stairs, treads, risers Safe window sills Safe handrails and grabrails Safe floor areas Safe outside paths and steps Safe doors and windows Adequate fencing of section Adequate fencing of pool Good location and operability of amenities	Falls associated with baths, etc Falling on level surfaces, etc Falling on stairs, etc Falling between levels Vehicle injuries in driveways Drowning in pools Collision and entrapment Poor ergonomics and operation of amenities	Visual inspection by trained assessor Measurement of key dimensions (stairs, decks, windows, handrails, paths, pools and fences)	Injuries and avoidable deaths in home‡
Adequate safety from fires, electrocution and explosion: Safe and functional energy source Safe and functional electrical and gas installations Safe and functional wood burner, fire place, chimneys[33] Smoke alarms[34] Adequate escape route and exit ways Hot water less than 55°C	Electrical hazards Fire Flames, hot surfaces, etc Explosions	Visual inspection by trained assessor Test water temperature at hot tap Test smoke detectors	Burns, scalds, electrocutions and avoidable deaths in home
Adequate warmth and dryness: Optimal orientation Adequate insulation Adequate draft stopping Adequate heating Adequate site/subfloor drainage[35 36] Adequate ventilation Minimum indoor temperature	Damp and mould growth[37] Excess cold[13]	Visual inspection by trained assessor Measure thickness of ceiling insulation Test of moisture levels in walls	Excess winter hospitalisations and deaths Asthma
Adequate protection from excess heat: Optimal orientation and shading Adequate insulation Adequate ventilation Safe heating facilities Safe cooking facilities	Excess heat	Visual inspection by trained assessor	Excess summer hospitalisations and deaths
Adequate lighting and sunlight: Adequate natural lighting Adequate artificial lighting	Inadequate or excessive lighting Inadequate sunlight exposure	Visual inspection by trained assessor Measurement of light intensity	Falls at home Reduced sleep and psychological well-being Vitamin D deficiency and associated illnesses

Figure 20 Keall et al (2010) Links between housing quality features, hazards and likely outcomes (health, safety, sustainability)

Housing quality feature measured	Hazards associated with housing	Method of measurement	Health, safety and sustainability outcomes
Adequate control of indoor pollutants: Minimum asbestos products No lead paint Water pipes free from lead Minimum combustion products Minimum VOCs	Asbestos and manufactured mineral fibres Lead paint,[38—41] pipes[42] Biocides (eg, timber treatments) Carbon monoxide and fuel combustion products Uncombusted fuel gas Volatile Organic compounds—for example, formaldehyde Radiation*	Visual inspection by trained assessor-especially noting where building material has deteriorated, releasing fibres into the air Testing of paint for lead content Measurement of VOCs with hand-held device (although the concentration is highly variable over time, making them difficult to measure[43])	Acute toxicity or asphyxiation Respiratory illnesses Range of chronic illnesses
Adequate protection from noise: Minimum internal noise sources Adequate insulation from external noise sources	Noise	Visual and aural inspection by trained assessor	Reduced sleep[7] and psychological well-being Potential chronic illnesses§
Adequate security, privacy and space: Secure windows and doors Adequate privacy from neighbours Adequate space for personal activities such as study	Entry by intruders Inadequate space Inadequate privacy	Visual inspection by trained assessor Measurement of floor area	Assaults at home Reduced sleep and psychological well-being Impaired educational attainment
Addresses energy efficiency: Adequate insulation Optimal orientation to sun Effective, sustainable heating Sustainable and non-polluting energy sources (eg, solar water heating)	Environmental degradation (global warming; depletion of natural resources; environmental pollution)	Visual inspection of insulation in ceiling, walls, floor All heating sources listed	Environmental well-being
Adequate sustainability of water use and waste disposal: Water-saving technology Collection and reuse system for rainwater Sustainable sewage disposal Specific area for storage of recycling	Environmental degradation (global warming; depletion of natural resources; environmental pollution)	Collection of rainwater not currently noted Visual inspection of stormwater and site drainage	Environmental well-being

*Radon is a significant cause of cancer in Europe[44] but barely present in countries with geologies such as New Zealand.
†Earthquake hazards not addressed in much detail in the British Housing Health and Safety Rating System, as earthquakes rare in the UK—they are covered by Hazard No 29, Structural Collapse and Falling Elements.
‡All injury hazards, with the exception of drowning hazards, are included in the English Housing Health and Safety Rating System.
§http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2007/08/23/noise123.xml

Figure 21 Links between housing quality features, hazards and likely outcomes (health, safety, sustainability) (continued)

Source: Nix et al (2020)

No.	Household hazard	Method of identification	Indicator
1	Damp and mould	Dwelling survey	Extent of mould on internal/external surfaces
2	Heat	IEQ monitoring/occupant survey	Recorded temperature and perceived comfort during summer
3	Cold	IEQ monitoring/occupant survey	Recorded temperature and perceived comfort during winter
4	Indoor air pollution	Dwelling survey/occupant survey	Location of cooking, ventilation provision and perceived air quality
5	Asbestos	Dwelling survey	Presence of asbestos
6	Overcrowding	Dwelling survey/occupant survey	Number of occupants in the given space
7	Security/intruders	Dwelling survey	Presence of locks and bars on openings
8	Inadequate lighting	IEQ monitoring/dwelling survey/occupant survey	Level of lighting (lux) and perceived lighting
9	Noise	Occupant survey	Perceived noise levels and building permeability
10	Mosquitoes	Dwelling survey	Presence of open water storage and drains
11	Domestic hygiene	Dwelling survey	Quality of kitchen facilities and location of drains
12	Pests	Dwelling survey	Presence of pests
13	Food safety/infestations	Dwelling survey	Presence of refrigerator
14	Sanitation and drainage	Dwelling survey	Quality of bathing facilities
15	Personal hygiene	Dwelling survey	Presence of toilet and sanitation system
16	Water supply	Dwelling survey	Water source type
17	Falls	Dwelling survey	Ergonomics of staircase, use of space and levelling of the floor
18	Electrical shocks	Dwelling survey	Quality of electrical fittings, exposed wires and proximity of water
19	Fire	Dwelling survey	Location of cooking area, cooking fuel used and quality
20	Collision and entrapment	Dwelling survey	Ergonomics of dwelling and space
21	Structural collapse	Dwelling survey	Quality of the dwelling structure

Figure 22 Nix et al (2020) Method of identification and indicator for each household hazard

Appendix H

Source: US HUD (2023)

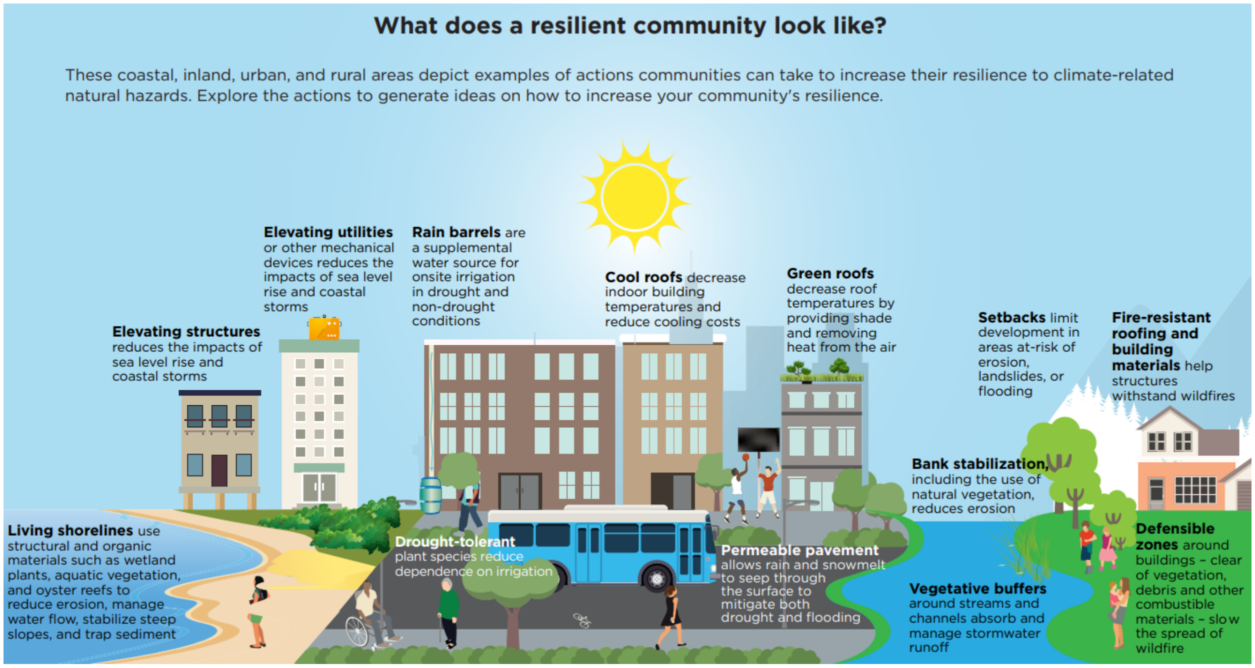

Figure 23 US HUD (2023) Community Resiliency

References

1. *Why the Built Environment – Architecture 2030*. (n.d.). https://www.architecture2030.org/why-the-built-environment/
2. *Incremental housing, and other design principles for low-cost housing*. (2016, November 1). International Growth Centre. https://www.theigc.org/publications/incremental-housing-and-other-design-principles-low-cost-housing
3. Afaq Hyder Chohan, Adi Irfan, Jihad Awad, Open house international vol. 40 no. 4, December 2015. Development of Quality indicators of Housing Design (QIHD) an approach to improve Design Quality of affordable Housing.
4. Brundtland, G. H. (1987). *Report of the World Commission on Environment and Development: Our Common Future*. World Commission on Environment and Development. Retrieved December 1, 2023, from http://www.un-documents.net/our-common-future.pdf
5. Crawley, E., Cameron, B., & Selva, D. (2016). *System Architecture: Strategy and Product Development for Complex Systems*.
6. King, P. (2016). *In Dwelling: Implacability, Exclusion and Acceptance*. Routledge.
7. *A Blueprint for Addressing the Global Affordable Housing Challenge*. (October 2014). McKinsey Global Institute. https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Urbanization/Tackling%20the%20worlds%20affordable%20housing%20challenge/MGI_Affordable_housing_Executive%20summary_October%202014.pdf
8. Dose of Good Ads. (2020, July 18). *VELUX『The Indoor Generation』* [Video]. YouTube. https://www.youtube.com/watch?v=H381cBJYZPY

9. Sara Topelson de Grinberg. (2004). *El Estado de la Vivienda en México – 2004.* Centro de Investigación y Documentación de la Casa (CIDOC). https://www.cidoc.org/publicacion.php?p=eavm-2004

10. Herbert, C., Belsky, E., & DuBroff, N. (2012). *The State of Mexico's Housing – Recent Progress and Continued Challenges.* Joint Center for Housing Studies of Harvard University.

11. Sara Topelson de Grinberg. (2022). *Estado Actual de la Vivienda en México 2021.* Centro de Investigación y Documentación de la Casa (CIDOC). https://www.cidoc.org/publicacion.php?p=eavm-2021

12. Reyes, A. (2020). Mexico's housing paradox: Tensions between financialization and access. *Housing Policy Debate*, *30*(4), 486–511. https://doi.org/10.1080/10511482.2019.1709879

13. Market, R. E. (n.d.). *La hipoteca verde es una realidad*. Real Estate Market & Lifestyle. https://realestatemarket.com.mx/articulos/credito/12421-la-hipoteca-verde-es-una-realidad

14. *HIPOTECA VERDE y SISEVIVE-ECOCASA*. (n.d.). Secretaría De Desarrollo Agrario, Territorial Y Urbano. https://www.gob.mx/cms/uploads/attachment/file/32462/Presentation1_COP21_SEDATU.pdf

15. Sara Topelson de Grinberg. (2023). *Estado Actual de la Vivienda en México 2022.* Centro de Investigación y Documentación de la Casa (CIDOC). https://www.cidoc.org/publicacion.php?p=eavm-2022

16. Lemmens, C., & Luebkeman, C. (2016). *Circular Economy in the Built Environment*. Arup. https://www.arup.com/perspectives/publications/research/section/circular-economy-in-the-built-environment

17. Velázquez Robles, J. F., Picó, E. C., & Hosseini, S. M. A. (2022). Environmental performance assessment: A comparison and improvement of three existing social housing projects. *Cleaner Environmental Systems*, *5*, 100077. https://doi.org/10.1016/j.cesys.2022.100077

18. Chan, A. P., & Adabre, M. A. (2019). Bridging the gap between sustainable housing and affordable housing: The required critical success criteria (CSC). *Building and Environment*, *151*, 112–125. https://doi.org/10.1016/j.buildenv.2019.01.029

19. Gan, X., Zuo, J., Wu, P., Wang, J., Chang, R., & Wen, T. (2017). How affordable housing becomes more sustainable? A stakeholder study. *Journal of Cleaner Production*, *162*, 427–437. https://doi.org/10.1016/j.jclepro.2017.06.048

20. Ibem, E. O., & Aduwo, E. B. (2013). Assessment of residential satisfaction in public housing in Ogun State, Nigeria. *Habitat International*, *40*, 163–175. https://doi.org/10.1016/j.habitatint.2013.04.001

21. Pullen, S., Arman, M., Zillante, G., Zuo, J., Chileshe, N., & Wilson, L. (2010). Developing an assessment framework for affordable and sustainable housing. *Australasian Journal of Construction Economics and Building*, *10*(1/2), 48. https://doi.org/10.5130/ajceb.v10i1/2.1587

22. Pullen, S. et al., 2009. *Ecocents living: affordable and sustainable housing for South Australia*, APO: Analysis & Policy Observatory. Australia. Retrieved from https://policycommons.net/artifacts/10761015/ecocents-living/11638515/

23. De Azevedo, N. J. D., & Rêgo Silva, J. J. (2010). DEFINITION OF INDICATORS FOR SUSTAINABLE SOCIAL HOUSING: IN SEARCH OF a MODEL. *Journal for Housing Science*, *34*, 79–92. https://www.researchgate.net/profile/Jose-Rego-Silva/publication/288112076_Definition_of_indicators_for_sustainable_social_housing_In_search_of_a_model/links/5edfeba345851516e6658000/Definition-of-indicators-for-sustainable-social-housing-In-search-of-a-model.pdf

24. Charoenkit, S., & Kumar, S. (2014). Environmental sustainability assessment tools for low carbon and climate resilient low income housing settlements. *Renewable & Sustainable Energy Reviews*, *38*, 509–525. https://doi.org/10.1016/j.rser.2014.06.012

25. Fuhry, L., & Wells, W., A.I.C.P. (2013). *Green Goes Mainstream in Low-Income Housing Planning, 79*(9), 31-35. https://www.proquest.com/trade-journals/green-goes-mainstream-low-income-housing/docview/1462508436/se-2

26. Winston, N., & Pareja-Eastaway, M. (2007). Sustainable housing in the urban context: International Sustainable Development Indicator sets and Housing. *Social Indicators Research*, *87*(2), 211–221. https://doi.org/10.1007/s11205-007-9165-8

27. *Portfolio of EU social indicators for the monitoring of progress towards the EU objectives for social protection and social inclusion.* (2015). European Comission. https://socialprotection.org/discover/publications/portfolio-eu-social-indicators-monitoring-progress-towards-eu-objectives

28. *Housing in Europe – 2023 interactive edition.* (2023). Eurostat. https://ec.europa.eu/eurostat/web/interactive-publications/housing-2023

29. *ECUVE 2.0*. (n.d.). INFONAVIT. Gerencia de Investigación Aplicada y Divulgación de Métodos. https://www.clusterdeviviendaguanajuato.org/wp-content/uploads/2018/12/ECUVE.-2.0.pdf

30. Boström, M. (2012). A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue. *Sustainability : Science, Practice and Policy*, *8*(1), 3–14. https://doi.org/10.1080/15487733.2012.11908080

31. Dempsey, N., Bramley, G., Power, S., & Brown, C. (2011). The social dimension of sustainable development: Defining urban social sustainability. *Sustainable Development*, *19*(5), 289–300. https://doi.org/10.1002/sd.417

32. Eriksson, A. B. (2016). *RESIDENTIAL USABILITY AND SOCIAL SUSTAINABILITY towards a paradigm shift within housing design?* [Thesis for the degree of licentiate of architecture, CHALMERS UNIVERSITY OF TECHNOLOGY]. https://publications.lib.chalmers.se/records/fulltext/230228/230228.pdf

33. Epimakhova, T. (2014). *Designing for Multigenerational Community: Creating a supportive environment for young and old in the U.S.A.* [Master of Science in Architecture, Clemson University]. https://tigerprints.clemson.edu/all_theses/2411/

34. Kim, S., Lee, S., & Ahn, Y. H. (2019). Evaluating Housing Maintenance Costs with Loss-Distribution Approach in South Korean Apartment Housing. *Journal of Management in Engineering*, *35*(2). https://doi.org/10.1061/(asce)me.1943-5479.0000672

35. Lee, K., Ahn, Y., & Chae, C. (2014). Establishment of the repair cycle of the components of the apartment housing. *KIEAE Journal*, *14*(2), 69–75. https://doi.org/10.12813/kieae.2014.14.2.069

36. Harding, J. P., Rosenthal, S. S., & Sirmans, C. F. (2007). Depreciation of housing capital, maintenance, and house price inflation: Estimates from a repeat sales model. *Journal of Urban Economics*, *61*(2), 193–217. https://doi.org/10.1016/j.jue.2006.07.007
37. *721 Housing Quality Indicators (HQI) Form*. (2008). THE NATIONAL AFFORDABLE HOMES AGENCY. Retrieved December 1, 2023, from https://assets.publishing.service.gov.uk/media/5a7d4f82e5274a2af0ae2d57/721_hqi_form_4_apr_08_update_20080820153028.pdf
38. Monahan, J. L., & Powell, J. (2011). An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings*, *43*(1), 179–188. https://doi.org/10.1016/j.enbuild.2010.09.005
39. Zhao, H., & Magoulès, F. (2012). A review on the prediction of building energy consumption. *Renewable & Sustainable Energy Reviews*, *16*(6), 3586–3592. https://doi.org/10.1016/j.rser.2012.02.049
40. Ren, Z., Jian, A., & Chen, D. (2023). Development of an energy rating tool for Australian existing housing. *Energies*, *16*(21), 7368. https://doi.org/10.3390/en16217368
41. Moghayedi, A., Phiri, C., & Ellmann, A. (2023). Improving sustainability of affordable housing using innovative technologies: Case study of SIAH-Livable. *Scientific African*, *21*, e01819. https://doi.org/10.1016/j.sciaf.2023.e01819
42. Pihelo, P., Kuusk, K., & Kalamees, T. (2020). Development and performance assessment of prefabricated insulation elements for deep energy renovation of apartment buildings. *Energies*, *13*(7), 1709. https://doi.org/10.3390/en13071709

43. Keall, M., Baker, M. G., Howden-Chapman, P., Cunningham, M., & Ormandy, D. (2010). Assessing housing quality and its impact on health, safety and sustainability. *Journal of Epidemiology and Community Health*, *64*(9), 765–771. https://doi.org/10.1136/jech.2009.100701
44. Nix, E., Paulose, J., Shrubsole, C. et al. Evaluating Housing Health Hazards: Prevalence, Practices and Priorities in Delhi's Informal Settlements. *J Urban Health.* 97, 502–518 (2020). https://doi.org/10.1007/s11524-020-00442-w
45. McConkey, S. A., & Larson, E. R. (2022). Measuring community disaster resilience over time. *Journal of Homeland Security and Emergency Management*, *19*(3), 281–321. https://doi.org/10.1515/jhsem-2021-0064
46. Mohamed, B. E., & Carbone, C. (2022). Mass Customization of Housing: A Framework for Harmonizing Individual Needs with Factory Produced Housing. *Buildings*, *12*(7), 955. https://doi.org/10.3390/buildings12070955
47. Samanani, F., & Lenhard, J. (2019). House and home. *Cambridge Encyclopedia of Anthropology*. https://doi.org/10.29164/19home
48. Ellsworth-Krebs, K., Reid, L., & Hunter, C. (2015). Home -ing in on domestic energy research: "House," "home," and the importance of ontology. *Energy Research & Social Science*, *6*, 100–108. https://doi.org/10.1016/j.erss.2014.12.003
49. Sixsmith, J. (1986). The meaning of home: An exploratory study of environmental experience. *Journal of Environmental Psychology*, *6*(4), 281–298. https://doi.org/10.1016/s0272-4944(86)80002-0
50. Stoneham, Bryce & Smith, Desmond. (2015). The house and the home: The balance of architecture and psychology within the residential home.

https://www.researchgate.net/publication/282854099_The_house_and_the_home_The_balance_of_architecture_and_psychology_within_the_residential_home

51. López-Durán, F. (2018). *Eugenics in the garden: Transatlantic Architecture and the Crafting of Modernity*. University of Texas Press.
52. Atmodiwirjo, P., & Yatmo, Y. A. (18-20 November 2015). Architecture as machine; towards an architectural system for human well-being. In *Universitat Politecnica De Valencia*. Le Corbusier: 50 Years Later | International Congress, Valencia, Spain. http://dx.doi.org/10.4995/LC2015.2015.679
53. *International Code Council. (2018). 2018 International Energy Conservation Code (IECC). https://codes.iccsafe.org/content/iecc2018/chapter-4-re-residential-energy-efficiency*
54. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2017). *ANSI/ASHRAE Standard 55-2017: Thermal Environmental Conditions for Human Occupancy*. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/55_2017_d_20200731.pdf
55. Connell, B. R., Jones, M., Mace, R., Mueller, J., Mullick, A., Ostroff, E., Sanford, J., Steinfeld, E., Story, M., & Vanderheiden, G. (1997, April 1). *THE PRINCIPLES OF UNIVERSAL DESIGN*. THE CENTER FOR UNIVERSAL DESIGN. N.C. State University. Retrieved December 1, 2023, from https://web.stanford.edu/class/engr110/2007/PUD.pdf

56. Anacker, K. B., Carswell, A. T., Kirby, S. D., & Tremblay, K. R. (Eds.). (2018). *Introduction to Housing*. The University of Georgia Press. https://ugapress.org/book/9780820349688/introduction-to-housing/

57. *Community Resilience Toolkit*. (January, 2023). U.S. Department of Housing and Urban Development. https://www.hudexchange.info/resource/5981/community-resilience-toolkit/

58. Le Corbusier. (1985). *Towards a New Architecture*. Dover Publications, Inc. Reprint. Originally published in London: J. Rodker, 1931.