REIMAGINING BUILDING EFFICACY: AN EXPLORATORY STUDY

by

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A Dissertation

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Lyles School of Civil Engineering

West Lafayette, Indiana

August 2022

THE PURDUE UNIVERSITY GRADUATE SCHOOL
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This dissertation is dedicated to my family; Sheldon, Melvin, and Rhonda.

ACKNOWLEDGMENTS

I am grateful for the mentorship and teachings offered by my dissertation committee. I am especially appreciative of their openness and ongoing – financial and academic - support to pursue this original research topic. I am expressing my deepest and most sincere gratitude to Dr. Joseph V. Sinfield and Dr. W. Travis Horton for their collective knowledgebase, opinions, and advisership critical for the research advancement. Thank you Prof. Sinfield for the sustaining and enriching conversations, and cheer. Thank you Prof. Horton for your encouragement, flexibility, and thoughtful conversations. Prof. Eckhard A. Groll, I am thankful for the sense of belonging, and global citizenship you afforded me. Prof. Karthik Kannan's I am much obliged for the formal education and insights into new perspectives, literature, and tools to designing for outcomes. Thank you Dr. Curtis Taylor for sparking and nurturing my early interest in research. Thank you Dr. Daniel Bampoh, Dr. Jucun Liu, Dr. Yu-chung Lin, Romika, and the rest of the Enabling Innovation Lab for your friendship, and invaluable research tools and insight.

I am thankful for the foundational love and support from Jesus Christ provided through my living family, and the prayers of the deceased. Sheldon Anderson has been a limitless source of strength, joy, love, and information for which I am immensely grateful. Thank you parents, and siblings - Melvin, Rhonda, Melvin II, Melvin L., and LaShanda - for your utmost faith and confidence. I am appreciative to my in-laws – Clyde, Yolande, and Sherise – for your continued encouragement, love, support. I offer gratitude to my nieces, Kendall and Kennedy, for their inspiration to continue this work and improve their future. Thank you Grandma Tunie, Grandma Hattie, Grandma Millanee, Auntie Mazie, Grandma Ruth, Goddy, and Goddy Nita for being exemplary models of commitment and love for the family and the community. Thank you Tiffany, Dr. Nelson James, Supriya, Ularee, and Bianca for the laughter, cheer, and amazing times.

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NOMENCLATURE

B^{t}	Benefit in year t
$\mathrm{B}_{\mathrm{development}}$	Benefit of development for the developer
$\mathrm{B}_{\mathrm{home}}$	Explicit and intangible homeownership benefits
$\mathrm{B}_{\mathrm{outcomes}}$	Benefit of building outcomes
$\mathrm{B}_{\mathrm{A2,outcomes,SOCIETY}}$	Benefit of building outcomes for society in scenario A2
$\mathrm{B}_{\mathrm{B2,outcomes,SOCIETY}}$	Benefit of building outcomes for society in scenario B2
$\mathrm{B}_{\mathrm{outcomes,UC}}$	Benefit of building outcomes for a utility company
$\mathrm{B}_{\mathrm{renting}}$	Benefit of renting
$\mathrm{C}_{\mathrm{home}}$	Costs of homeownership
$\mathrm{C}_{\mathrm{development}}$	Costs of development
$\mathrm{C}_{\mathrm{land}}$	Cost of land
$\mathrm{C}_{\mathrm{outcomes}}$	Cost of building outcomes
$\mathrm{C}_{\mathrm{A2,outcomes,SOCIETY}}$	Cost of building outcomes for society in scenario A2
$\mathrm{C}_{\mathrm{B2,outcomes,SOCIETY}}$	Benefit of building outcomes for society in scenario B2
$\mathrm{C}_{\mathrm{premium}}$	Cost premium
$\mathrm{C}_{\mathrm{renting}}$	Cost of renting
C^{t}	Costs in year t
EB	Explicit benefits
EC	Explicit costs
n	Number of different attributes
NPV	Net present value
$\mathrm{NPV}_{\mathrm{A1,DEVELOPER}}$	Net present value for the developer in scenario A1
$\mathrm{NPV}_{\mathrm{A2,DEVELOPER}}$	Net present value for the developer in scenario A2
$\mathrm{NPV}_{\mathrm{B1,DEVELOPER}}$	Net present value for the developer in scenario B1
$\mathrm{NPV}_{\mathrm{B2,DEVELOPER}}$	Net present value for the developer in scenario B2
$\mathrm{NPV}_{\mathrm{A1,OWNER\ OCCUPIER}}$	Net present value for the owner-occupier in scenario A1
$\mathrm{NPV}_{\mathrm{A2,OWNER\ OCCUPIER}}$	Net present value for the owner-occupier in scenario A2

$NPV_{A2,SOCIETY}$	Net present value for the society in scenario A2
$NPV_{A2,UTILITY\ COMPANY}$	Net present value for the electricity provider in scenario A2
$NPV_{B1,TENANT}$	Net present value for the tenant in scenario B1
$NPV_{B2,TENANT}$	Net present value for the tenant in scenario B2
$NPV_{B2,SOCIETY}$	Net present value for the society in scenario B2
$NPV_{B2,UTILITY\ COMPANY}$	Net present value for the electricity provider in scenario B2
$PV(B)$	Present value of benefits
$PV(C)$	Present value of cost
s	Discount rate
t	Year
$\acute{w}_i$	Not-normalized ratio weight
w_i	Normalized ratio weight is the importance weight of the *i*th attribute
$v(x)$	Multi-attribute utility for alternative x
$v_i(x_i)$	Value of alternative *x* on *i*th attribute

ABSTRACT

This dissertation focuses on the creation of a paradigm shift in building innovation. Challenges in achieving building energy-efficiency at scale highlight the complexity of the building performance problem, which is embedded with social, cultural, physical, environmental, and economic factors. Traditional approaches to building design have difficulty accounting for these multi-faceted variables and related longitudinal barriers and intangible impacts. Firstly, key stakeholders and their economic constraints change throughout time, and this variability is not traditionally considered upfront or addressed throughout a building's operation. Secondly, buildings have social, cultural, environmental and economic implications that are difficult to quantify and evaluate against strictly functional design objectives. Therefore, current deeply technical and often system-specific building design strategies could benefit from whole-building solutions that account for this complexity and enable a paradigm shift in design toward human-centered outcomes (i.e., well-being, health, financial sustainability) and effective (i.e., equitable and sustainable) buildings.

To drive this shift, an impact-based innovation framework was employed to pursue system-level and ecosystem-level strategies to optimize longitudinal building value assessment and distribution. First, a grounded theory study was pursued which identified gaps in current design practice that miss underlying building subsystem interactions which influence building performance. A system-level taxonomy of the building was then defined, linking identified sub-system synergies to functional, emotional and social building benefits for inhabitants. Then, an exploratory mixed-methods study was pursued, yielding a longitudinal building value framework that helps characterize key stakeholders, building design choices, and shared efficacy metrics. Building on these inputs, a multi-stakeholder, longitudinal building value assessment model was developed. The model was tested on two residential building development scenarios, highlighting its ability to capture the true impact of buildings on affected stakeholders over time in terms of tangible and intangible building costs and benefits. Finally, business model innovation concepts were employed to identify specific changes in stakeholder value delivery and capture strategies that could redistribute building costs and benefits over time, and thereby facilitate a shift in the paradigm of design and value capture in the residential building industry

1. INTRODUCTION

1.1 The Building Performance Challenge

The buildings sector accounts for one-third of global final energy consumption, making it responsible for one-third of total direct and indirect energy-related carbon dioxide emissions (IEA, 2013, p.25). Reducing building-related energy consumption and carbon emissions is challenging because the building is a complex system, and the compounded interaction of technologies almost always influences energy demand (IEA, 2013). As a solution to this challenge, historically, building energy efficiency policies have focused on end-use products (i.e., heating equipment, lighting, and appliances). However, expansion of the built environment and increasing ownership of energy-consuming equipment has offset energy-efficiency gains (IEA, 2013, p.25). This consequence can be characterized using general systems theory, in that improving only a part of the system does not improve the performance of the whole and could even diminish it. As such, there is a significant shift towards focusing on systems-level performance or whole-building performance to achieve of higher levels of performance, breakthrough systems and materials, and financial benefits (IEA, 2013). At the whole-building level, energy efficiency is one of many building performance metrics, further complicating solutions to the problem.

Moreover, building performance depends on spatiotemporal, physical, social, and economic factors, and balancing these interactions is a multi-faceted challenge. This work comprehensively addresses this challenge by employing system-level and ecosystem-level approaches to enable system-level innovation for improved system-level performance. Systems-level methods support building performance-oriented design and can serve as complementary approaches to traditional architectural design and sustainability and have the highest potential for innovation due to the exploitation of synergies (Hensel, 2012).

1.2 Research Motivation

This research was motivated to disentangle, frame, and improve the longitudinal misalignment of a building's value among key stakeholders. The building value is the net benefit a stakeholder can receive from building design improvements. The nested concept of value spans the spectrum of stakeholders that can benefit from the intentional improvement of a system or process and the outcome of that system or process; and business models are mechanisms for entities to identify, create, capture, convey, deliver, protect, sustain, and manage value (Liu et al., 2021). The value received by stakeholders associated with a building is ultimately linked to design choices that affect the way a building is constructed, used, and disposed of. System design choices can influence and shape downstream end-user decisions (Proctor, & Van Zandt, 2008, p. 291). End-user decisions and occupant behavior are influenced by physical environmental variables (i.e., building design), socio-cultural and technical-economic variables. The current modular strategy pursued in building design produces practical upstream and downstream issues potentially impairing building performance. Upstream in the building life (i.e., design and development), buildings are designed with conflicting or elusive goals and metrics. Downstream in the building life (i.e., operation, demolition, and disposal), buildings are not designed with enough granularity to fully capture occupant needs and decisions or the technological interactions ultimately affecting energy demand and other building-related outcomes. This work explored if the behavioral, economic, social, environmental, physical, and cultural impacts of buildings can be proactively shaped through design by connecting design choices to value-based or outcome-focused metrics and temporally aligning the building-related financial benefits/costs with building beneficiaries throughout the building's lifecycle. This perspective may be helpful to influence building performance as the opportunity to affect its performance is highest in the early design stages and decreases dramatically over time (Kohler & Moffatt, 2003).

1.3 Conceptual Overview of the Study

With this motivation in mind, this work focused on answering the question: *How do we identify and quantify the impact of the key processes and factors that entrain the performance of a building (complex system) and subsequently improve the building (system) performance?*

The presented research to answer this question is outlined in Figure 1. The current (initial) state of building design and use, and the steps taken to test hypotheses toward the goal, integrated state between building design factors and stakeholders are displayed in this figure and described below. This question led to the following key sub-questions, and research streams, described below and in Figure 1:

1. How can we improve building (system and subsystem) design to achieve impact-based performance metrics?

    a. What are the gaps in performance capabilities caused by the current design paradigm?
    b. What are the direct counter-intuitive or obscure synergies that have implications on outcomes?
    c. How do buildings affect the people who use or are in proximity to them?
2. What are the business challenges and constraints in delivering building performance?
    a. What resources can be leveraged to improve building outcomes? How?

Research stream 1: Study to design for efficacy

Hypothesis 1: Building design can enable direct stakeholders to consistently attain favorable net positive benefits in human-related performance dimensions using impact-focused, user-centered metrics (i.e., well-being, health, financial sustainability, and productivity).

Objectives

1. Establish an expanded, system-level view of synergies influencing building performance
    a. Identify comprehensive, system-level interrelationships between building parts, including potential system-level impacts of the building on occupants
    b. Find opportunities for innovation in the linkages to close human-related performance gaps
2. Establish a socio-technical, spatio-temporal, longitudinal model of building use and performance
    a. Characterize direct stakeholders, building outcomes and value, and the stakeholder ecosystem
    b. Derive efficacy metrics and indicators that connect stakeholders
    c. Develop a method to assess the building value
3. Recommend how innovation in building design can achieve efficacy metrics
    a. Connect building design and features to the delivered value
    b. Propose new avenues for research to study building

Research stream 2: Study of value creation in the ecosystem

Hypothesis 2: Business models in the residential real estate industry can enable downstream and upstream stakeholders to consistently attain favorable net positive building benefits using business model innovation.

Objective

1. Explore alternative business models for the development of effective, sustainable buildings

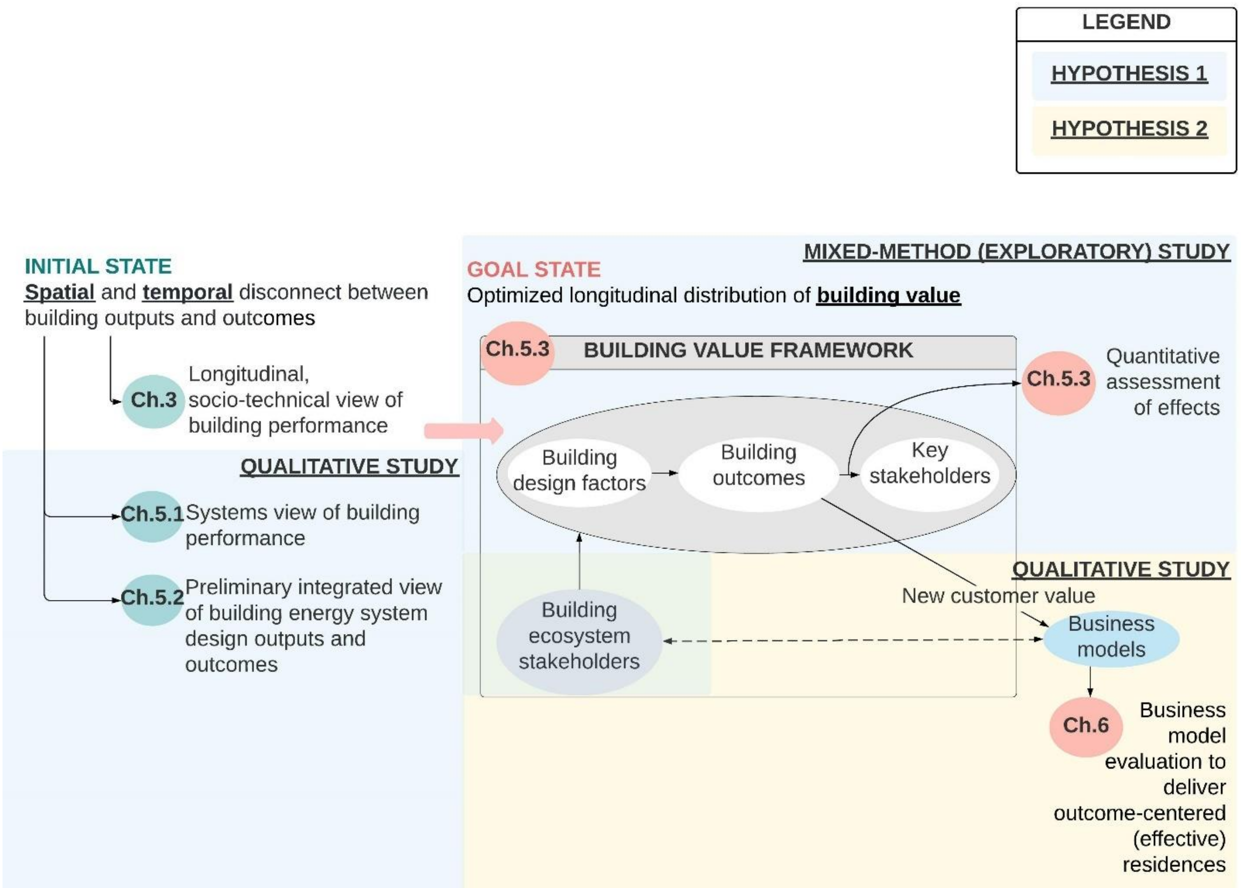


Figure 1: Conceptual overview of the research

1.4 Significance of the Study (Research Scope, Contribution, and Broader Impacts)

1.4.1 Research Scope and Contribution

The contribution of this work is a systematic, end-to-end innovation strategy for the development and evaluation of impact-focused building solutions encompassing the following components:

1. Systems-oriented view of building performance and design gap identification
2. Model of critical human-building engagement factors and shared building efficacy metrics to building performance
3. Development of new business levers for sustainable building performance

The total contribution of these outputs yields the conceptualization of longitudinal value assessment as an approach to change underlying economics and solutions to yield intentionally effective and sustainable research, design, and performance. This contribution may be a beneficial approach to design and assess the holistic impact of solutions in housing or industries with patterns of longitudinal value such as pharmaceuticals and healthcare.

Buildings are a component of a complex network of socio-technical systems that establish the growth economy (Hensel, 2012) and are the source of our ecological woes (Crocker & Lehmann, 2013). The actual costs and benefits of correcting or replacing these systems are confounding and nested with consumerism unsustainable behaviors in the engine of the growth economy (Hensel, 2012). The broader contribution of this work is to relieve this anguish through building design innovation and business model innovation. First, designing for efficacy metrics expands the building design paradigm from a modular to integrated innovation archetype allowing for the generation of enabling innovations (e.g., high-impact focused innovations) that achieve higher levels of systemic, whole-building performance in specific contexts. Second, innovative building development strategies promote the adoption of effective and efficient buildings under practical constraints. Collectively, this work enables building-level solutions to support residential LEED sustainable city and community metrics. Also, this work has three lateral benefits: a new approach to designing and developing engineered systems embedded with complexity due to human and economic factors and impacts (relevant in systems problem-solving and design science literature); insight into the impact of individual building operations, and their complex network of activities (relevant to smart cities development (Hensel, 2012)); and insight into building impacts in non-OECD settings (appropriate in sustainable development literature). Forget & Lebel (2001) expressed that sustainable increased adoption of development requires alignment between business interests, the well-being of people, and the ecosystem's survival; this research promotes and enables such alignment.

Broader Impact

The work calls attention to patterns of longitudinal value creation and its importance as a problem-solving lens that can spur innovation and new research avenues. Another impact of this work is the idea of characterizing intangible impacts due to their significance in seizing a practical understanding of consumption to influence design decisions and performance measures.

2. BACKGROUND

2.1 The Need to Reimagine Sustainable Building Performance

The need to reimagine sustainable building performance[1] was published by Lumpkin et al. (2020). Sustainable (or green) building design is the primary system-level approach to integrating and improving the physical (e.g., energy) and human (e.g., indoor environmental quality) impacts of buildings. Green buildings are "designed, built, and operated to enable an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life" (USGBC, 2018). Leadership in Energy and Environment Design (LEED) is a popular green certification program, rating system, and "framework that creates healthy, highly efficient and cost-saving green buildings" (LEED, n.d.). Green buildings may also be high-performing buildings (HPBs). HPBs are "buildings that address human, environmental, economic, and total societal impact resulting from the application of the highest-level design, construction, operation and maintenance principles—a paradigm change for the built environment" (National Institute of Building Sciences, 2008). This longitudinal, integrated approach to building design results in performance variability and missed performance targets – human and technical - as described below.

A significant amount of evidence highlights that green buildings are not necessarily more energy-efficient than their conventional counterparts. Analysis of data for 100 LEED-certified commercial and institutional buildings supplied by the USGBC and the New Buildings Institute (NBI) showed that on average, 28-35% of LEED buildings used more energy, and 18-39% used less energy per floor area compared to their conventional counterparts (Newsham et al., 2009). Additionally, the measured energy performance had little correlation with the number of energy credits awarded during design or the building certification level. This study also suggested an opportunity to improve the green building rating scheme to ensure consistent, favorable outcomes at the individual building level. Scofield (2009) analyzed other LEED building energy consumption data and concluded there were no significant primary energy savings than non-LEED buildings and therefore no improved environmental impact. However, the site energy consumption

[1]Adapted from Holistic Synergy Analysis for Building Subsystem Performance and Innovation Opportunities, Lumpkin et al. (2020) in *Building and Environment*

was 10-17% lower for LEED-buildings than their conventional counterparts. Scofield (2013) investigated 21 office buildings in New York City, NY, and concluded that LEED Silver and Certified office buildings underperformed other New York City, NY office buildings. LEED buildings certified at the Gold level outperformed comparable New York City, NY office buildings by 20%. Menassa et al. (2011) investigated 11 LEED-certified U.S. Navy buildings designed to comply with the Executive Order (EO) 13423 mandated a 30% reduction in energy consumption by 2015. Nine of the 11 buildings did not achieve a 30% reduction in electricity consumption. The authors recommended further investigation to understand why LEED points obtained for Energy, and Atmosphere attributes did not correlate with energy savings for these buildings. Oates & Sullivan (2012) studied 47% of Arizona's 53 LEED New Construction (NC) building population and compared their energy performance with the existing building population. The Arizona LEED NC sample maintained the average national source energy use intensity (EUI). Six LEED NC high energy intensity (HEI) laboratories were 35% less efficient in site energy and 14% less efficient in source energy use than the national laboratory building stock. The LEED NC medium energy intensity (MEI) buildings outperformed the national site EUI average by 13% but consumed primary energy on par with national averages. Except for "public assembly" and "office" buildings, the LEED NC MEI sample outperformed comparable structures' of similar climate site EUIs. The two "public assembly" buildings in the sample were 50% worse than similar zone-specific structures. The site EUI for ten office buildings was 1% less efficient than comparable zone-specific buildings. Four out of 19 buildings with building energy models outperformed the baseline model. One out of the 19 outperformed the design model. The study's results established to industry practitioners and researchers that the LEED NC rating system's energy strategies fail to meet modeled efficiencies.

LEED-certified buildings are promoted to have higher occupant satisfaction with indoor environmental quality than conventional buildings; however, this depends on the occupant and the building (Gou et al., 2013). Green building performance may not achieve higher indoor environmental quality compared to its conventional counterpart. Abbaszadeh et al. (2006) surveyed 215 buildings in the U.S., Canada, and Finland, involving 33,285 respondents and concluded that, on average, occupants in green buildings were more satisfied with thermal comfort and air quality in their workspace. However, the average satisfaction scores with lighting and acoustic quality were comparable to the non-green average. In green buildings, more people were dissatisfied with light levels and sound privacy. Gou et al. (2012) also determined that green buildings may not consistently improve comfort and productivity relative to non-green buildings. A study comparing two green buildings with 235 total respondents and a conventional building with 72 respondents in Shenzhen, China, observed that while the green buildings achieved higher satisfaction on health and productivity perception than conventional buildings, one of two studied green buildings had significantly more noise than the conventional building and the other green building suffered from more inferior lighting quality than the conventional building. Relatedly, Altomonte & Schiavon (2013) assessed occupant responses (10,129 in LEED buildings) across the US, Australia, Canada, Finland, and Italy. This study observed that occupants of LEED-certified buildings have equal satisfaction with the building overall and with the workspace to occupants of non-LEED buildings, highlighting no significant influence of LEED certification on occupant satisfaction IEQ. However, occupants in LEED buildings were more satisfied with air quality and slightly more dissatisfied with light. Bordass & Leaman (1997) and Gou et al. (2013) observed that green building users tend to tolerate deficiencies with IEQ more than in conventional buildings – meaning that dissatisfaction with one or more aspects of the environment does not necessarily produce dissatisfaction with the overall environment – and assess the performance overall by balancing the good features against the bad. The tolerance of discomfort in green buildings was driven by the building users' ability to control the physical environment. Khoshbakht et al. (2018) conducted a systematic investigation of 25 post-occupancy studies and reviewed global evidence to examine whether green buildings were more satisfactory than non-green buildings. The evidence was inconclusive as the results varied across studies. Sample size, occupancy period, and green features are discussed as the primary sources of inconsistency across studies. The study did, however, recognize two global themes: (1) "green building occupants exhibited significantly higher satisfaction than non-green buildings in the Orient (mainly China and South Korea)" and (2) "no significant difference in occupant satisfaction between green and conventional buildings in the Occident (primarily the US and UK)." The study authors concluded that these observations might stem from a baseline that is high in the Occident and somewhat lower in the Orient, making variations relative to the baseline less or more significant, respectively.

The need for design innovation in the built environment has been deservedly expressed. It has not yet taken place at the individual building level, only in the built environment, organization, or individual level, as subsequently discussed. Crocker & Lehmann (2013) explored the interactions between behavior and consumption in their psychological, social, and material contexts and the design capabilities to reshape and reconfigure the dependent relationships at different scales and contexts to enable sustainability. It was shown that shifting consumption to design-led, community-based social innovation, shared-use product-service systems, and systemic design-led interventions are potential remedial avenues to motivate change toward sustainability. These practices have short-term benefits and potentially have more significant longer-term positive impacts. Sevaldson (2013) called for enhanced systems perspectives on the built environment to achieve higher levels of innovation and sustainability Potentially, improved perspectives would meld systems thinking and practice with design thinking and practice, including qualitative, quantitative integrated, and generative methods to approaching complexity, involve a planning process that accounts for the dynamic change over time, provide a view of the processes and flows that captures relationships between different scales and categorically separated items. Hensel (2013) discussed the value of performance-oriented design as a framework for reforming architectural practice and innovation research. This design paradigm would need to address the human subject, the environment, and the spatial and material organization to attain sustainability. Dunin-Woyseth & Nilsson (2013) discussed the emergence of research by design research in architectural and urban design. Reviewed case studies highlighted that the advantage of this research approach is that a diverse set of cultural practices engaged in by a specific group of designers and design intellectuals will develop from the studies. Lu & Sexton (2009) created a conceptual knowledge-based innovation model for small construction professional practices as a system-oriented framework to investigate how to create, manage, and utilize innovation.

Performance variability in traditional and green buildings constitute the need for performance-oriented, strategic innovation in building design. Downstream stakeholders and host communities would benefit from improved strategies.

2.2 Introduction to Design Science and Design Models for Innovation

Design science provides an opportunity to reframe building performance to capture the diverse set of related influential spatio-temporal factors and illustrate potential solution paths to enhance performance. Design science (DS) is a holistic and systematic form of designing used as a problem-solving approach or a planning tool with a specific path. The premise is to take a holistic and integrative view of a system's parts and problems and redesign the system to prevent the host of problems – in the ecosystem, system use, and system implementation - by employing mathematical or systematic logic (Pérez Romero, 2017). Many DS approaches are considered design-based innovation approaches, methodically emphasizing the dimension of value. There is a nested concept in these approaches to deliver value for the spectrum of stakeholders in the intentional improvement of a system/process and outcome of that system/process. These approaches "humanize" the innovation process by understanding people, their goals and concerns, their aspirations and motives, and the world surrounding them (Van Der Bijl-Brouwer & Dorst, 2017). DS approaches can bridge the gap between practice and academia by developing actionable knowledge grounded in evidence (Holloway et al., 2016).

A form of design science research has been applied across several social and technical systems: information and communication technology systems (Vaishnavi et al., 2015) (Hevner et al., 2004), organization and management (Bate, 2007) (Holloway et al., 2016), healthcare business intelligence systems (Kao et al., 2016), tourism design (Fesenmaier & Xiang, 2017), and on a performance-oriented workplace e-learning system (Wang et al., 2011). For example, design-based approaches to innovation are applied practically to change processes, services, and products: in the private sector to support businesses in gaining competitive advantage and in social and public sectors to address complex societal issues – often called "social innovation" in the field of public policy. An appropriate design science framework would be a vehicle to reframe human and technical issues related to building performance and new solution space.

2.3 Design Science Framework Selection

Available design-based innovation approaches and their relevant limitations needed to be understood. As such, popular holistic and systematic design-based innovation approaches - biomimicry, design for X (DFX), and human-centered design (HCD) methods – were evaluated. According to the Biomimicry Institute, biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies. DFX is a product development approach where design activities are centered around a goal "X": a life phase (e.g., manufacture, assembly) or a product feature (e.g., quality, sustainability). HCD methods (e.g., user-experience design and design thinking) support the design of useful, usable, pleasurable, meaningful products or services for people (Van Der Bijl-Brouwer, & Dorst, 2017). HCD methods gain and apply knowledge about humans and their environment to design products or services that meet their needs and aspirations. User-experience (UX) design focuses on digital interaction and conducting empathetic research to help define problems and derive innovative solutions (Nedeltcheva & Shoikova, 2017). UX design enhances the capability of an object - communication, space, or interface – to meet the user's need through a thorough understanding of its role in an end user's task and environment, incorporated from design to development (B.-N.Sanders, 2002) (Usability.gov, n.d.). Design thinking is a strategic, holistic problem-solving approach that enables designers to "match what is desirable from a human point of view, with technologically feasible and available resources within the practical constraints of business" (Dam & Siang, 2019). Grounded in the area of design, it combines a holistic user-centered perspective with rational and analytical research to create innovative solutions (Dam & Siang, 2019). Design thinking reaffirms the privileged role of the designer, positioning them as the officer shaping the ambiguity into a clean configured solution (Iskander, 2018). DFX and HCD methods can be applied to this research problem, but they minimize situational complexity and therefore are not ideal for framing this research. For example, DFX techniques are inherently reductionist by focusing on a specific feature/life phase and excluding others (Holt & Barnes, 2009). This confining approach can result in a single perspective improvement of a solution, counter the creation of sought meaningful, holistic solutions, and potentially disconnect from solutions from the same X activity or other DFX activities. Likewise, HCD methods often create a gap between user research and design practice because design from anthropometric data does not indicate how a product was used (only how it will not or cannot be used), usability evaluations are typically done in product testing labs providing limited insight into in situ use, and context-oriented research methods do not provide straightforward answers to designers (Van Der Bijl-Brouwer, & Dorst, 2017). Similarly, design thinking is limiting because it is fundamentally conservative and preserves the status quo (Iskander, 2018).

Considering the standard design innovation approach limitations and the gap in building design innovation, the Enabling Thinking Framework (ETF) is employed to frame this research. The ETF is an organized approach to an end-to-end design process model tied to innovation outcomes (Solis & Sinfield, 2018). This design process comprises stage-specific design behaviors, and core behaviors focused on achieving impactful innovations. The characteristic patterns of enabling innovations informed the identification of the design patterns and behaviors described in the framework. Design behaviors are the combinations of individual instances/elements or work that represent thoughts and actions (Solis, 2015). Design patterns are the collection of design behaviors (Solis, 2015). This design process assumes design as a goal-oriented activity but diverges from other design processes in retaining that the type of the desired outcome (e.g., an innovation archetype) can be unambiguously achieved using innovation patterns to guide design activities. The archetypes provide patterns that serve as boundaries for the pursuit of solutions throughout the design process (Solis, 2015).

This model has similarities and fundamental differences from the design for innovation model school of thought. Similarities include using a comprehensive systems approach, framing the problems in individual and personal ways, solution generation, design process strategy, and designing from first principles (Solis, 2015) (Solis & Sinfield, 2018). The enabling thinking model includes problem definition, information gathering, generation of alternatives, analysis, evaluation and selection, communication, and implementation (Solis, 2015). The dissimilarity from established design process models is the addition of two processes essential to attaining a specific innovation outcome: 1) defining a vision, 2) defining a path (Solis & Sinfield, 2018). On the former, defining a vision means creating a strategy and visualizing the results for design activities to help guide design activities. Design strategies are likely to be more effective if tailored toward the specific type of impact sought from a particular kind of innovation. This initial stage can help designers intentionally operate within the selected innovation model patterns throughout different design process stages, which is especially important to framing the need. On the latter, defining a path for ideas means designing their implementation throughout the design process. Creating a set of intended actions to translate ideas into reality will help scope and compare resources required for an idea and identify potential synergies between ideas. This activity is an intermediate step between design/innovation solution evaluation, selection and communication, and its actual implementation in practice.

Contrary to other approaches, the ETF yields: 1) organizational adaptability 2) designer positionality 3) management of uncertainty 4) integrated, contextually and culturally independent solutions 5) strategic value production 6) continuous, deliberate, impact-focused activities. It also allows for knowledge production and intellectual inquiry. This framework links theory to practice and consistently attempts to modernize both through each other and allows knowledge production to focus and pursue emergent research problems.

The following is an overview of the design patterns specific to designing for an enabling innovation as well as its departures from established design approaches (Solis, 2015) (Solis & Sinfield, 2018):

1) Envisioning stage: outlining a strategy for the enabling innovation to manage innovation efforts
2) Problem definition stage: from framing the problem to framing the flaws in the paradigm
3) Gathering information stage: from researching "relevant" information to a specific problem to proactively researching the technical, economic, systems, sociological and physical forces surrounding the problem that influence its success
4) Generating alternatives stage: from generating ideas fluently to connecting generalized first principles to proactively broadening idea spaces
5) Modeling and analysis stage: from modeling deep system features to ensuring the host ecosystem is addressed
6) Evaluation and selection stage: from a focus on solution tradeoffs to matching solutions to application contexts that generate early trial and impact
7) Communication stage: from facilitating acceptance or practice of enabling innovation to the resulting paradigm shift
8) Path definition stage: creating an implementation plan based on emergent strategy principles with the unique goal of simultaneously unfolding performance, impact, and worldview/paradigm change in the enabling window.
9) Implementation stage: deploy the emergent strategy to build the enabling innovation concept

The ETF is well-suited to reframe the building performance challenge and subsequent solution paths because the current deeply technical building design and technology strategies could benefit from a comprehensive view of building performance and targeted impact. Firstly, the model highlights macro-level and micro-level perspectives of techno-economic and socio-technical paradigm changes. The building has social, cultural, environmental, and economic implications that are difficult to quantify and evaluate against functional design objectives. This research may help overcome the barrier that traditional building design approaches have in concretely designing for the intangible impacts of buildings. Secondly, the model reinforces that innovation is attained as individuals and organizations have the capabilities to realize and match market demand (societal needs/demands) with (technological/non-technological) solutions. The framework structure should facilitate the matching process between the solution, societal needs, categories, and contexts. This characteristic enables solutions crossing scales and contexts, connecting upfront stakeholders to design implications. Thirdly, the model "focuses on the often-ignored opportunities to make early decisions that shape the future impact of an innovation, influence its timing, and its potential for success" (Solis, 2015). This model characteristic helps consider the longitudinal stakeholder variability upfront and connect the economic constraints for critical stakeholders who change over the building life. Lastly, this model characterizes how enabling innovation can be a driver for a paradigm change. Ideally, individually the enabling technologies/solutions can unfold to make a difference in society through a cascade of impact benefits. This aspect of the model helps assess the applicability of potential building solutions in other contexts.

The research investigation is structured to achieve the ETF patterns, design behaviors, and recommended actions described in Tables B1, C1, D1. Due to its convergent formation, the application of the ETF positions this work to lead the systematic pursuit of confluent, impactful solutions that promote the growth of sustainable residential buildings.

3. LONGITUDINAL PERSPECTIVE OF BUILDING PERFORMANCE

Implementation science was employed to grasp the socio-technical-economic, and complex nature of human engagement with buildings and evaluate the effectiveness of engagements. Implementation science - often employed in health care and project management - is the study of methods and strategies to promote the uptake of interventions that have proven effective into routine practice, with the aim of improving population health (Nilsen, 2015) (Holliday, 2014) (Baxter et al., 2014) (Petersen et al., 2013) (Carroll et al., 2007). It promotes organizational, program, and industrial paradigm shifts to focus on outcomes from activities, and evaluation of existing programs. Problems associated with a single performance measure, energy-efficiency, were assessed to simplify information gathering and problem definition.

A re-orientation of building energy efficiency using implementation science as a construct captured the systems, technical, economic, socio, and psychological forces which yield building energy-efficiency challenges and a potential flaw in the current design paradigm, i.e., the "how" and 'why' socio-technical variables emerge and influence performance. This new perspective aided in visualizing and managing the socio-technical, spatio-temporal nature of building performance factors and categories for multiple building performance metrics; and highlighted how potential design interventions may yield enhanced building performance.

Potentially the complex interactions between building performance inputs and outputs hindering widespread and consistent building energy performance highlighted by the application of the ETF (see Appendix A) demand an expanded comprehensive approach to achieve building energy efficiency; one that broadens the notion that the technical design of building energy systems should be viewed in their integrated, meaningful capacity, grounded in the spatio-temporal, socio-technical nature of building performance, while considering energy-efficiency as an outcome among other outcomes. A framework to guide efforts toward addressing the flaw in the paradigm (i.e., the disconnect between outputs and outcomes), and toward measuring performance in terms of its impact accounting for and balancing the interrelatedness of the decision-making environment, and spatio-temporal, socio-technical variables influencing the performance of a complex system is presented in Figure 2. The systems, technical, economic, socio, and psychological forces that influence building energy efficiency were framed using implementation science. A portion of those qualitative results is visualized in the building system logic model in Figure 2.

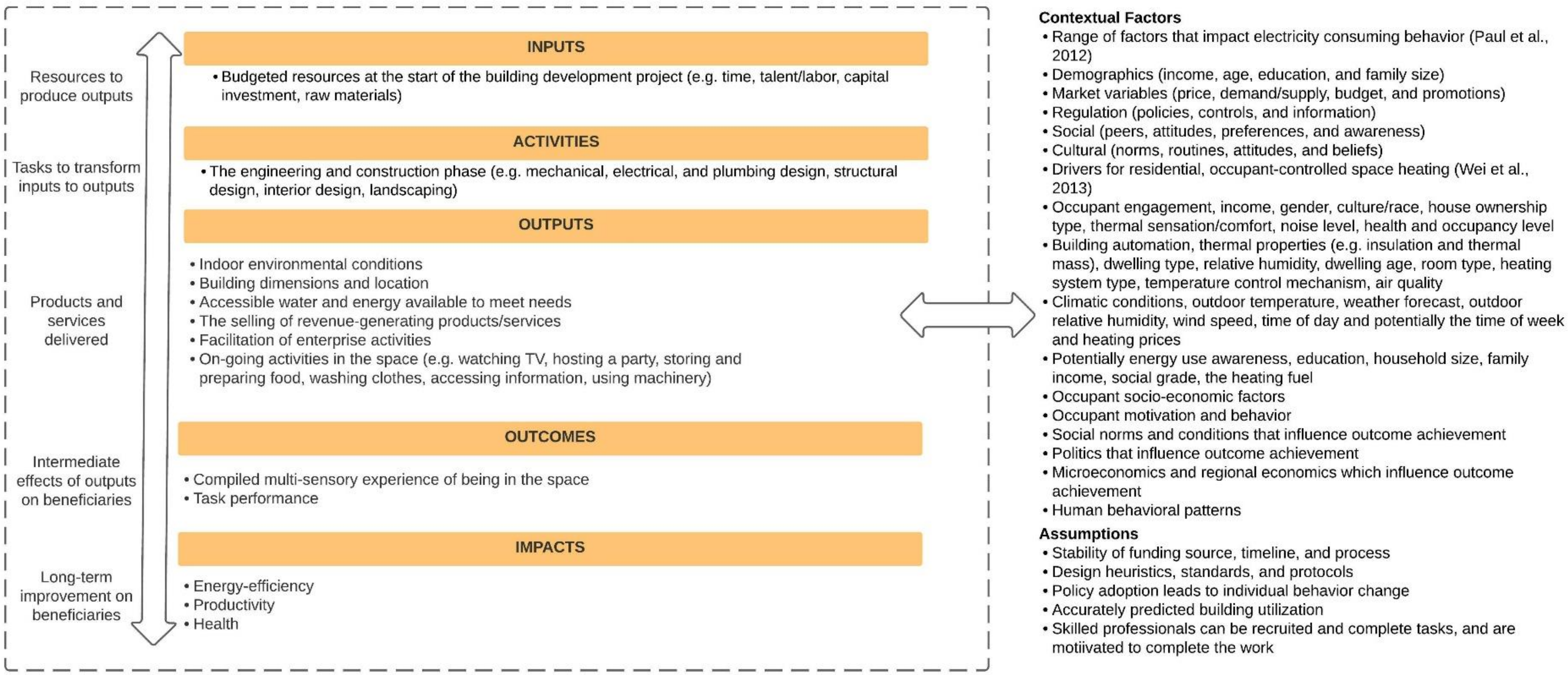


Figure 2: Building system logic model

The definition of the building logic model components were adapted from The World Bank (2011), Petersen et al. (2013), and Ladd & Jernigan (2006), and applied to the longitudinal building context. There are inputs, activities, outputs, outcomes, impacts, contextual factors, key assumptions, and external factors that cause the building system's socio-technical performance. In project management, the project goals, objectives, or impacts are the overarching rationale for the project. These goals answer the question, "why are we doing this project." These objectives answer the question "why do beneficiaries in the building ecosystem interact with the building system" in the building context. There may be multiple – measurable and immeasurable - objectives for undergoing a project or building development. Building outcomes can be immediate to short-term effects on beneficiaries sought from building consumption. The multi-sensory experience of being in the space is a simple example of a building outcome. These outcomes should be measurable to gauge the success of a building toward the related stakeholder goal and several small measurements toward an overall project outcome. Target outcomes answer the question "what building engagement has achieved." Target outcomes are typically written in statements beginning with past tense words for a success measure's palpable definition. Project outputs are produced or delivered products and services and generally expressed as nouns. The purpose of building outputs is to achieve building system outcomes. In the building context, building outputs may be the delivered indoor environment quality conditions and building characteristics. Project management distinguishes outputs and outcomes by time and measurability (Westcott, 2008). Project outputs are considered complete upon delivery according to specifications; and outcomes are evaluated at different intervals post project completion. Project activities are the work required to turn inputs into outputs. Building activities are the actions set in motion by the developers and designers to produce the building outputs. An example of building activities is the work completed during the engineering and construction phase (e.g., mechanical, electrical, and plumbing design, structural design, interior design, landscaping). Activities can be segmented into early and later activities or segmented into smaller tasks and are written in the present tense using action verbs. Project inputs are initial resources. In the building context, these inputs are the budgeted resources supplied at the start of the building development project (e.g., time, talent/labor, capital investment, raw materials). Separately, each stakeholder carries a set of assumptions about how the building interaction will work. The external factors are the contextual conditions in which the building system is created and used over which there is little or no control over, and influence the performance of the building system and the achievement of outcomes. The building ecosystem includes the external factors that describe the building system (i.e., the situational aspects of consumption). Contextual factors include the business environment (e.g., competitor, customer, and supplier dynamics), consumer socio-economic factors, motivation, behavior, social norms, and micro- and regional economics, politics, and conditions that influence outcome achievement. The logic model conceptualizes the building ecosystem by distinguishing terms, definitions, and examples.

3.1 Socio-technical concepts: The Building System, Outcomes and Effectiveness

The introduction of building outcomes and impacts requires defining the concepts of building efficacy and effectiveness as contextual building system performance metrics (e.g., to capture the physical building's effect on humans). Building efficacy is the potential or intended ability to produce building outcomes for beneficiaries (e.g., the potential or intended result of building outputs on human needs). Building effectiveness is the actual extent to which the effects of building outputs are beneficial and achieve their intended value under real-world conditions. Efficacy is generally considered the power or capacity to produce effects; power to effect the object intended (Oxford English Dictionary Online, 2021). Effective is creating a notable effect; being powerful in effect; effectual (Oxford English Dictionary Online, 2021). Effectiveness is the quality of being effective (Oxford English Dictionary Online, 2021). Building efficacy is the performance of a building under ideal or predicted conditions. Building effectiveness is the building's performance in real-world conditions, and building performance is defined by the building's expected/measured effect on humans. Effectiveness can be synonymous with value creation; value creation is anything that positively increases the benefits received by beneficiaries (Davidow, 2018).

Due to human and physical interrelatedness of the building physics, technological challenges of building components, and the building energy efficiency drivers and inhibitors (described in Appendix E), it is beneficial to frame the building as a complex, socio-technical system. In this new frame, building - energy and non-energy consuming - systems are deterministic and animated, but their collective outputs serve social systems (e.g., individual, group, and societal needs). Many of the building subsystems may be classified as deterministic and animated, and the whole building serves social systems. A socio-technical system is one in which human beings are working together to achieve the goal of the organization (as in a social system) and, at the same time, to reach their aims (as in an animate system) (Ackoff & Gharajedaghi, 1996). Also, the output of each part is created due to the social and technical interaction between the parts, and both aspects must be jointly optimized for optimal performance and utility (Bauer & Herder, 2009). Lastly, designing the building as a socio-technical system requires accounting for social and technical factors influential to its functionality and usage. Therefore, *the building system includes the beneficiaries who receive a direct benefit or loss from engagement with a physical building and the set of characteristics of the physical structure that enable people to use technology, gather information, make decisions, coordinate and communicate with others*. *The building ecosystem is formed by the building system and the external factors that describe the building system's environment.*

The logic model suggests that the combination of the building development and operation phase inputs, activities, and outputs created a set of outcomes and impacts for the individuals and organizations invested in a specific building creating its ecosystem and socio-technical variables yielding performance. This logic model connects different beneficiaries relative to their interaction with the building system in terms of the variety of variables (e.g., physical, financial, emotional, and social variables) that connect them, resulting in socio-technical performance; and relates "how" and "why" socio-technical building performance emerges. Given this perspective of the building, the design of any building (and its subsystems) should consider the social and technical factors that influence the building's functionality and usage to optimize its performance and utility. The notion that the building – and its components - should be designed in terms of their meaningful capacity.

4. RESEARCH METHODOLOGY

Two qualitative studies and one mixed-methods study were conducted under the design science guidance of the ETF. The research methods seized the temporal and symbiotic nature of the building outputs and their outcomes in order to promote the intentional design changes and solutions for enhanced performance. One qualitative study explored if and how building component design could be improved for enhanced system-level building performance using a jobs-based systems approach. Next, a mixed-methods approach identified the building outcomes, building value, the building ecosystem, and a method to assess the diffusion of value to beneficiaries. Last, business model innovation qualitatively facilitated the systematic exploration of how the real estate industry may change business activities to profit from the new value proposition of building efficacy dimensions. The building role is positioned at a “system-level” in Chapter 5 and shifts to the “building-level” in Chapter 6 as the perspective of the framework shifts from a systems-view to an ecosystem-view.

4.1 Systems View of Building Performance

This qualitative study followed the logic of Charmaz's (2014) Grounded Theory (GT) methodology (see Footnote 1). Contrary to interviewing people like in a traditional GT study, this study used the academic literature as the data source and followed the data collection protocol in Figure 3 with a theoretical sampling technique in line with GT methodology. The purpose of this grounded theory study was to develop a theory that explains what remains in bridging the human-building interaction and performance gap for the building sector. The central phenomenon under study was underlying interactions between the humans that use conventional building systems and the resulting performance. For the remainder of the text, the term synergies denote interconnections with either positive or negative connotations and is synonymous with interactions. To expose the hidden assumptions on which the current modular building design paradigm is predicated, this research answered the questions, “How well are current building subsystems designed for system-level performance, and what are the potential innovation opportunities to close the human-building interaction and performance gap?” Sections 5.1.1 and 5.1.2 introduces a system-level construct of the building. The initial coding logic entailed data segmentation using codes with words/phrases reflecting expected jobs-to-be-done by the building (e.g., controllable heating and cooling systems) instead of applying pre-existing categories (e.g., HVAC systems), or system-level performance metrics (e.g., energy efficiency). Therefore, the initial codes reflected the data of interest – conventional building systems and system-level performance metrics - from a systems perspective. The potential gaps highlighted through the system-level construct are described in Section 5.1.4. Here, the building dynamics between individual building component outputs were analyzed to create a system-level profile of the resulting, emergent, whole-building behavior. First, 19 agent classifications for building components were generated to shift from traditional building component characterizations to system-level classifications based on their function relevant to the building's purpose. Then, the socio-technical, system-level dynamics between three building agents and all remaining agents and resulting performance outcomes were explored using a pairwise synergy assessment protocol. The data collection protocol in Figure 3 maps the search sequences and process. The focused coding subsumed the initial codes and framed the functional-social-emotional benefits of human-building interaction created from analysis of the initial codes in Section 5.2. This section includes a discussion of potential building innovation opportunities through 1) expansion of current design metrics to measurably achieve system-level outcomes based on the findings presented, and 2) proposition of a socio-technical structure of building component design objectives and potential directions for the intentional design of building impacts (e.g., system-level outcomes and implications).

Sequence Description

Sequence I: Synergetic evidence documentation sequence
List all agents involved in the synergy
Describe the synergetic outcome in terms of the performance metrics in Section 3.1

Sequence II: Building Design Accounting of Synergetic Sequence
Determine if the synergy is addressed in building codes
Determine if the synergy is addressed in buildings literature
Determine if it is captured from the end-users perspective

Data Collection Protocol

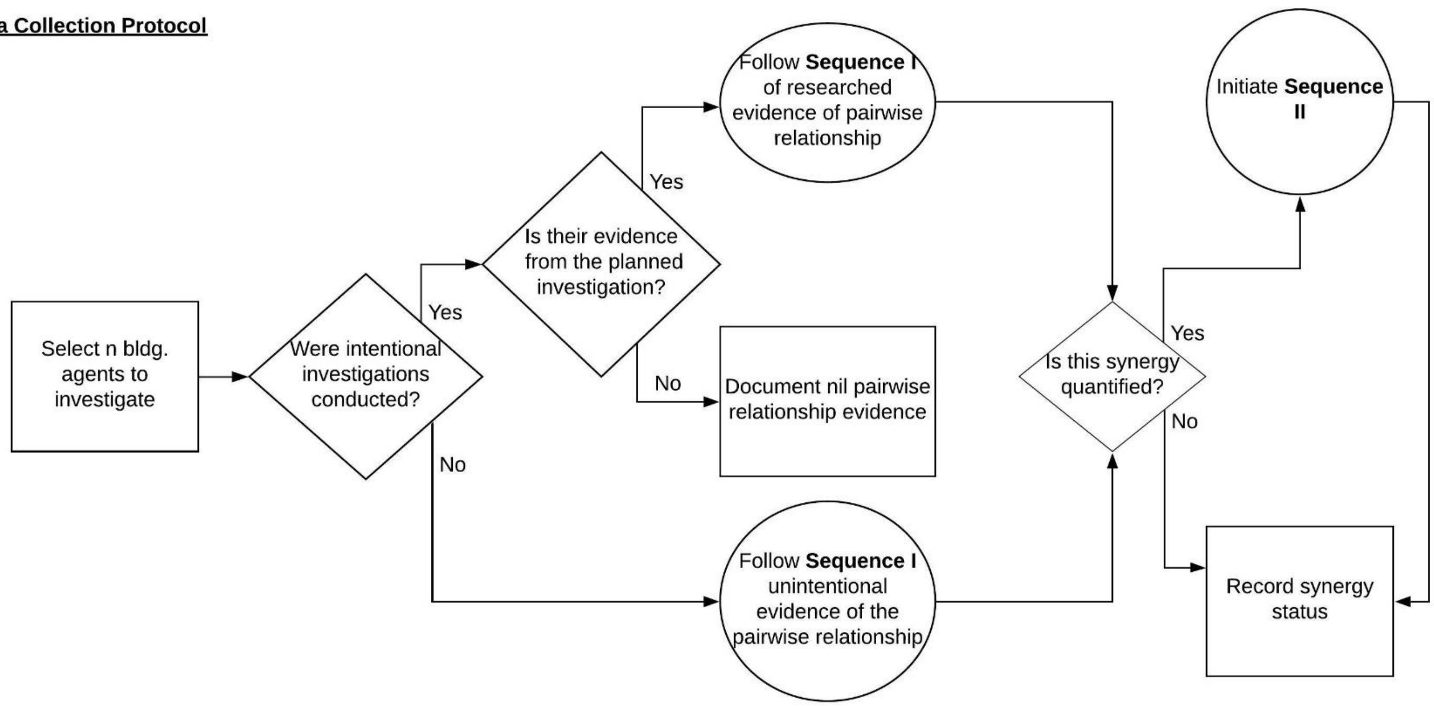


Figure 3: Process map to assess system-level pairwise relationships and accounting in building design

4.2 Outputs to Outcomes Mixed Methods Study

An exploratory sequential approach to study building efficacy was conducted to simplify the complexity of system-level variables influencing building outcomes and to integrate dissonant stakeholder needs. An overview of the study, the suitability of this research design, the theoretical base, and the philosophical foundation for this research design are subsequently discussed. The theoretical base for this study is the building efficacy gap in Appendices A-C and anchored in the systems view of building performance in Section 5.1. The philosophical foundation for using this approach and the theoretical perspective of the study positioned by a review of relevant building efficacy literature is summarized in Appendix A-C.

Mixed methods studies involve combining qualitative and quantitative research and data in a research study (Creswell, 2014). The exploratory sequential mixed methods design used herein determined the critical factors and implications of building performance by answering the overarching question, "how do the diverse set of socio-technical factors influence the set of potential building impacts?" There are three phases in this design; a qualitative phase, a quantitative feature development phase, and a quantitative test phase (Creswell et al., 2011). The researcher starts with the qualitative data collection and analysis, followed by a development phase of translating the qualitative findings into an approach or tool that is tested quantitatively in the third phase (Creswell et al., 2011). The researcher develops an instrument (e.g., variable, instrument, intervention, digital tool) in the intermediate step so the quantitative data collection can build on the qualitative data collection. As the name suggests, exploring a phenomenon occurs before the development phase to ensure the qualitative method can help inform the variables in the quantitative phase. The primary intent of this type of design is to develop and apply a quantitative measure grounded in qualitative data (i.e., in the views of beneficiaries). The primary data collection, analysis, and interpretation followed the procedures from Creswell et al. (2011, p. 344). The qualitative data collection and analysis in Phase I was conducted to understand the building outcomes and value from the stakeholder perspective in a multiple-case study and to connect that value to the initiating stimuli/features. The Phase I outcomes were inputted into a cost-benefit analysis (CBA) tool developed to evaluate the longitudinal building value in Phase II quantitatively. The longitudinal building value was tested using two residential building use scenarios, and a potential evaluation matrix to measure building effectiveness was developed in

Phase III. The recommended Creswell et al. (2011) qualitative and quantitative study procedures were followed and are subsequently discussed in Section 4.2.1 and 4.2.2.

This design was suitable for the research because (1) comprehensive, simultaneous measures, instruments, or experimental activities of building outcomes are unavailable; (2) the independent variables are unknown; (3) there is a lack of generalized guidance in designing for synergies affecting multiple building performance dimensions; (4) relevant variables need to be studied and quantified; (5) an emerging theory of the disconnected building value needed to be tested; and (6) the building value phenomenon needed to be thoroughly investigated, and its dimensions measured following the design suitability criteria in Creswell et al. (2011). Aligning with a requirement from the ETF, the emergent design of this study facilitated quantitative measure (and subsequent solutions) development from the qualitative insights. This design was particularly useful for communicating qualitative information to quantitative-biased audiences such as the Engineering community. The distinct study phases make the creation, implementation, and reporting periods clear. This design also allowed the researcher to identify a new conceptual framework, potentially sparking further investigations of building-level variables and relationships, investigating an evolving research question, and the transferability and generalizability of a newly developed solution.

The primary theoretical base for this perspective was the systems view of the building performance (see section 5.1). Building subsystem interactions were conceptually analyzed using jobs-based systems thinking and existing sustainable building design metrics by analyzing their pairwise interactions. As a result, building energy subsystems (e.g., HVAC, lighting systems) were connected to their functional, social, and emotional (F-S-E) benefits and non-energy consuming building parts. This evidence-based approach led to potential insight into how the current building design process may fail to capture the system-level synergies that can result in sub-optimal performance. Through this work, potential points of intersection between building agents and design opportunities to improve the building impact on humans as a direct performance measure were uncovered. This insight demanded the development of a building performance knowledge management scheme. The scheme in section 5.3 captures and describes potential building outcomes, the building system, and ecosystem and connects building-level interactions to impact-focused whole-building metrics from the beneficiary viewpoint to understand the building value developed.

The philosophical foundations for mixed methods research in this study are established using the Creswell & Plano Clark (2011) justifications. Various perspectives are employed in exploratory sequential design with a transition between phases. In the initial phase, the research problem demands a qualitative strand developed from constructivist principles. Constructivism in the first phase of the study emphasizes attaining a deep understanding of multiple perspectives. The influential - social, economic, cultural, and physical – variables critical in addressing their bearing on building performance are derived from multiple perspectives. The value in multiple perspectives is a gauge of building efficacy or stakeholder-valued dimensions performance dimensions derived from their experiences of the multi-variable interactions and resultant building-level effects. The loci of interactions act as a mechanism to manage an additional set of performance metrics endowing a new paradigm. Also, a constructivist philosophical assumption underpins the multiple case study approach employed as many outlooks arise during the research process. A post-positivist philosophical stance in the quantitative phase sets the assumptions and methodology toward measuring and analyzing variables for statistical trends to enhance the new paradigm empirically. A final interpretation of the two sets of connected results yields a dialectic perspective based on one set of assumptions.

Qualitative study method

The purpose of the multiple-case study is the identification of the immediate and long-term effects of building outputs on stakeholders (i.e., to examine how buildings impact people) toward the purpose of evaluating the potential design paradigm shift from a conglomerate of outputs to centralized outcomes and enabling this shift with management tools. The research was led by the hypothesis, "what are the critical socio-technical, spatio-temporal variables that influence building performance (i.e., how do buildings impact people)?" A hypothesis-driven systematic literature review of building performance and impacts in peer-reviewed scholarship and grey literature from engineering, management, and social science databases was conducted. The databases examined were ABI/INFORM Collection, EBSCO, Scopus. The literature search strategy involved three core/key guiding hypotheses:

A. Building performance depends on the social and technical variables of the building stakeholders and environment.

B. Buildings affect the economics, environmental, cultural, and health of people who use or are in proximity to them.
C. The value of buildings is dependent upon the needs and goals of the people (or stakeholders) who use them.

These hypotheses were structured into relevant keyword categories and compiled corresponding keyword synonyms to ensure an exhaustive literature search. The search terms in protocols Appendix F were applied to retrieve relevant open-ended data identifying the different purposes and contexts of building use. The search was limited to peer-reviewed and grey literature published in full texts in the English language only, screening and filtering out false positives (i.e., texts or journals unrelated to building performance). The selected texts were compiled into a building performance corpus of 1,561 selected publications to conduct automated content analysis. The compiled synonym lists in Appendix F were generated based on their proximal topic relevance to Owens et al. (2013) words and phrases with similar use cases and applied to the building performance corpus.

The automated content analysis employed a Latent Dirichlet (i.e., Semantic) Analysis (LDA) approach using a natural language processing code in program R to extract multilayered topic models representing multidimensional archetypes of conceptual themes from the building performance corpus. LDA topic modeling is a computational natural language processing technique for extracting abstract topical concepts from a corpus. It relies on an input Document-Term matrix that comprises two constituent matrices - a document-topic matrix and a topic-word matrix. The corpus text was partitioned and vectorized into matrices of tokens (i.e., individual words) associated with each document, recording corresponding frequencies of occurrence for each token in the corpus and grouping tokens into topics based on their co-occurrence frequencies to accomplish this. For additional topical granularity, the corpus was segmented into n-grams (i.e., noun-phrases) based on parts of speech of all words in the corpus. The n-grams were mined to extract phrases containing words that matched or corresponded to frequent building performance terms and synonyms phrases in Owens et al. (2013) The output n-gram terms extracted from the corpus were filtered and mined until saturation was achieved. Populated terms at frequencies of 10,360 through 100 and 3,046 through 45 from the purpose and context lists, respectively, were analyzed in two coding cycles as proposed by Miles et al. (2014). The first cycle coding method summarized data segments using the means-end model. The second cycle consisted of grouping the summarized data segments into a smaller number of categories, themes, or constructs to identify pattern codes.

The means-end model is employed to study consumers' perceptions and evaluations of products at varying levels in the means-end chain. The means-end chain is a procedural guide to specifically address the attributes connections to important consumer values. It was employed in this work as a guide to connect the tangible, concrete building attributes to the intangible, abstract personal and emotional stakeholder values. The means-end model served as a knowledge management scheme to generate themes that test the hypotheses for the reasons subsequently discussed, and it was helpful to segment the symbiotic variables associated with the purposes and the contexts of building use. The segmentation of product-use situational elements (e.g., building stakeholders and building environment) from consumption elements (e.g., consumers' expectation of performance) was beneficial to test hypothesis A. According to Gutman (1982), a fundamental assumption of the means-end model is "that consumers choose actions that produce desired consequences and minimize undesired consequences." Therefore, the building effects in hypothesis B were identified and positioned on the same basis for quantitative evaluation. Another fundamental assumption of the means-end model from Reynolds & Olson (2001) is "the connection of tangible, concrete product attributes to highly abstract and intangible personal and emotional values can be made through a chain of increasingly relevant abstract consequences that become increasingly personal, emotional, motivating, and self-relevant." This assumption enabled the assessment of the building value from a stakeholder's perspective to test hypothesis C. An additional fundamental assumption of the means-end model from Gutman (1982) is that "consumers evaluate product-use situations in terms of their potential impact over time, and the length of the time horizon the consumer adopts concerning the product-use situation can alter the importance of the consequences." Consequently, this model also aided with evaluating how building impacts may change over time. Separately, the term "outcomes" and "stakeholders" or "beneficiaries" are used in the context of buildings. Note these terms differ from the conventional corresponding means-end model terminology of "consequences" and "consumers".

The means-end model describes elements of building consumption in terms of the means-end chain. The product-use situation as described by Belk (1975) aided user, building, and situational variable segmentation. Users were the individual and organizations, and their related specific characteristics that are stable over time and places of observation is one segment. The transient, situational characteristics specific to a time and place of a use scenario is a second segment. The situational characteristics of Belk (1975) included "1) the physical surroundings, 2) social surroundings, 3) temporal perspective, 4) task definition, 5) antecedent state." The last segment is the variables that describe the lasting and general object features.

Quantitative study method

Two pairs of cost-benefit analyses (CBA) on residential development scenarios were evaluated. The CBA scenarios 1 and 2 were for a residential developer who sells a developed single-family detached home to an owner-occupier in Chicago, IL. The CBA scenarios 3 and 4 were for a multi-family building developer who leases residential spaces to tenants. A cost-benefit analysis (CBA) tool to quantitatively assess the impacts of residential buildings was developed following the methodologies presented in Boardman et al. (2018) and Steinemann et al. (2004). The CBA accounted for building impacts' affect on the utility of individuals who have standing, such as the developer, owner-occupier, or tenant. Governments and businesses may benefit from a residence's performance; therefore, exemplary residential development and building use externalities beneficial for the local and state government and the utility companies are included in the analyses.

The project costs and benefits constitute the CBA impact inventory in Tables 8 and 12, and detailed in Appendices I and J. The CBA impact inventories consist of scenario-specific residential building development and use tangible costs and benefits, intangible costs and benefits, and externalities identified from a review of scenario-specific economic literature. Also, the CBA impact inventories include the Phase I building outcomes and values. These impacts are tangible, intangible, and listed under "Building outcomes qualitative study results." Resources gained are the benefits, and resources lost are the costs. Tangible costs were the purchased resources or resources already owned by stakeholders with standing. Tangible benefits were revenue-generating resources or created, freed, or conserved resources by the project.

Impacts were monetized in terms of willingness to pay if possible or non-monetary values were captured using multi-attribute utility theory. The incremental monetary value of impacts on an annual basis was quantitatively evaluated over the building use duration; the equations are listed in Appendix G. The distributional implications of the longitudinal building value were estimated as the net present value (NPV) and decoupled net present value (DNPV). Relevant building costs (C) and benefits (B) during the building use period for each stakeholder were discounted to obtain the present value of benefits and costs that occur in year (t) using Eqs. (1) and (2). The net present value (NPV) was calculated using Eq. (3). The net present values for each scenario were computed using Eqs. (5)-(14) with Eq. (3) as a basis. Due to the increased riskiness of the proposed financial strategy for developers and other upstream stakeholders depending on the stage of the building use under evaluation, the decoupled net present value method in Eq. (4) was adopted from Espinoza & Morris (2013). The decoupled net present value method was presented to decouple potential risks and corresponding hesitancies to invest in the longitudinal building value due to the increased riskiness of the proposed financial strategy for developers and other upstream stakeholders depending on the stage of the building use under evaluation. The net present value for the developer and owner-occupier in scenario A1 were calculated using the explicit costs Eq. (5) and benefits and Eq. (6). The net present value for the developer and owner-occupier change in scenario A2 by considering the explicit (tangible) and intangible benefits and costs of land, development, homeownership, and building outcomes in Eq. (7) and Eq. (8). The net present value of an apartment building for tenants and developers were investigated in scenarios B1 and B2. In scenario A1, only explicit stakeholder costs and benefits were considered in Eqs. (10) and (11). In scenario B2, the explicit (tangible) and intangible benefits and costs – of development, ownership, and renting – and building outcomes relevant for each stakeholder were considered in Eqs. (12) and (13). Externalities were considered in scenarios A2 and B2 resulting in net present values were performed for society, in Eqs. (9) and (14), and the utility provider described in Ch. 5. Sensitivity analyses to determine if the net present value sign changes for key assumptions at discount rates ranging from 0-15% were conducted. The DNPV assumptions, and scenario B2 sensitivity analyses are shown in Appendix K.

Separately, Multi-Attribute Utility Theory (MAUT) was employed to quantify the impact of non-monetary building outcomes. Each decision-making stakeholder has an alternative or option, each option is constituted of value-relevant building attributes, such as those determined from the means-end model in Phase I. These attributes can be elicited from stakeholders and structured as salient characteristics (e.g., living room size, or the number of bedrooms), attribute levels (e.g., 300 ft^2, 350 ft^2, or 2, 3, 4 bedrooms), and with attractiveness scores. Higher scores on an appropriate value scale indicate more attractiveness for a specific attribute. The importance of each attribute is separately elicited. For example, alternative x may be a 2-story house with three bedrooms, and alternative y may be a 1-story house with four bedrooms. A 1-story house may be more attractive than a 2-story house. Also, the decision maker may consider the number of levels in the house more important than the number of bedrooms. Then weights, w_i, were calculated using Eq. (15) and assigned to each attribute to compute the single-attribute utility, v(x), for an alternative using Eq. (16). The results' robustness was tested using the equal weights method. The MAUT methodology of von Winterfeld & Edwards (1986) was applied to the context residential multi-criteria decision making by Jansen (2011). The Jansen (2011) methodology was applied in this research. The inputs and assumptions for each scenario are detailed in Ch. 5.

$$\mathrm{PV(B)} = \sum \frac{\mathrm{B}^t}{(1+s)^t} \tag{1}$$

$$\mathrm{PV(C)} = \sum \frac{\mathrm{C}^t}{(1+s)^t} \tag{2}$$

$$\mathrm{NPV} = \mathrm{PV(B)} - \mathrm{PV(C)} \tag{3}$$

$$\mathrm{DNPV} = \frac{(\widetilde{\mathrm{V}}_t - \tilde{R}_{\mathrm{V}t}) - (\widetilde{\mathrm{I}}_t - \tilde{\mathrm{R}}_{\mathrm{I}t})}{(1+r)^t} \tag{4}$$

$$\mathrm{NPV}_{\mathrm{A1,DEVELOPER}} = \mathrm{EB}_{\mathrm{development}} - (\mathrm{EC}_{\mathrm{land}} + \mathrm{EC}_{\mathrm{development}}) \tag{5}$$

$$\mathrm{NPV}_{\mathrm{A1,OWNER\ OCCUPIER}} = \mathrm{EB}_{\mathrm{home}} - \mathrm{EC}_{\mathrm{home}} \tag{6}$$

$$\mathrm{NPV}_{\mathrm{A2,DEVELOPER}} = \mathrm{B}_{\mathrm{development}} - \left(\mathrm{C}_{\mathrm{land}} + \mathrm{C}_{\mathrm{development}}\right) * \mathrm{C}_{\mathrm{premium}} \tag{7}$$

$$\mathrm{NPV}_{\mathrm{A2,OWNER\ OCCUPIER}} = (\mathrm{B}_{\mathrm{home}} + \mathrm{B}_{\mathrm{outcomes}}) - (\mathrm{C}_{\mathrm{home}} + \mathrm{C}_{\mathrm{outcomes}}) \tag{8}$$

$$\mathrm{NPV}_{\mathrm{A2,SOCIETY}} = \mathrm{B}_{\mathrm{outcomes,SOCIETY}} - \mathrm{C}_{\mathrm{outcomes,SOCIETY}} \tag{9}$$

$$\mathrm{NPV}_{\mathrm{B1,DEVELOPER}} = \left(\mathrm{EB}_{\mathrm{development}} + \mathrm{EB}_{\mathrm{ownership}}\right) - \left(\mathrm{EC}_{\mathrm{development}} + \mathrm{EC}_{\mathrm{ownership}}\right) \tag{10}$$

$$\mathrm{NPV}_{\mathrm{B1,TENANT}} = \mathrm{EB}_{\mathrm{renting}} - \mathrm{EC}_{\mathrm{renting}} \tag{11}$$

$$\mathrm{NPV}_{\mathrm{B2,DEVELOPER}} = \left(\mathrm{B}_{\mathrm{development}} + \mathrm{B}_{\mathrm{ownership}} + \mathrm{B}_{\mathrm{outcomes}}\right) - \left(\mathrm{C}_{\mathrm{development}} + \mathrm{C}_{\mathrm{ownership}} + \mathrm{C}_{\mathrm{outcomes}}\right) \tag{12}$$

$$\mathrm{NPV}_{\mathrm{B2,TENANT}} = \mathrm{B}_{\mathrm{renting}} + \mathrm{B}_{\mathrm{outcomes}} - (\mathrm{C}_{\mathrm{renting}} + \mathrm{C}_{\mathrm{outcomes}}) \tag{13}$$

$$\mathrm{NPV}_{\mathrm{B2,SOCIETY}} = \mathrm{B}_{\mathrm{B2,outcomes,SOCIETY}} - \mathrm{C}_{\mathrm{B2,outcomes,SOCIETY}} \tag{14}$$

$$\mathrm{w_i} = \frac{\acute{w}_1}{\sum_{i=1}^{n} \acute{w}_1} \tag{15}$$

$$\mathrm{v(x)} = \sum_{i=1}^{n} \mathrm{w_i v_i(x_i)} \tag{16}$$

4.3 Business Model Innovation Study

This study answered the second half of the research question: "how can building performance be improved" or "how can the residential real estate industry be altered to improve the stakeholders' sought outcomes?" The business model innovation (BMI) process proposed by Wirtz & Daiser (2018) facilitated the development of potentially achievable business strategies to improve building efficacy. The BMI process phases and recommended activities are listed in Table 1 with the executed research activities and methods. Holistic coding method content analysis was guided by the resilient complex adaptive system business model framework of Liu et al. (2020). The business model data was sourced from companies' annual 10-K reports and websites and publicly available documentation. The research explored the first five phases of BMI - analysis, ideation, feasibility, prototyping, and decision-making - but the final two phases, implementation, and sustainability can only be accurately explored through actual building development. A methodical assessment of the feasibility of new business models was guided by the wheel of business model reinvention proposed by Voelpel et al. (2004).

The business model construct of Liu et al. (2020) was purposefully employed to decipher how companies identify, create, convey, deliver, protect, sustain, and manage value for permutation of new models because of its robust conceptualization of business models. This business model construct enabled the deconstruction of 12 business cases: ten residential real estate companies, and two non-real estate company business models. The deconstruction of the models are presented in Appendix L. The ten residential real estate business cases were purposefully selected within the Global Industry Classification Standard (GICS) sub-industries of interest. The BMI focus was on residential buildings. Therefore, the GICS sub-industries of interest were Homebuilding, Residential Real Estate Investment Trusts (REITs), Real Estate Management & Development, and Engineering and Construction companies. The Homebuilding sub-industry is composed of residential construction companies. According to S&P Global & MSCI (2018) residential REITs are "companies or trusts engaged in the acquisition, development, ownership, leasing, management, and operation of residential properties in including multi-family homes, apartments, manufactured homes, and student housing properties." Companies in the Real Estate Management & Development sub-industry "develop real estate and sell the properties after development" (S&P Global & MSCI, 2018). The ten real estate cases were AvalonBay Communities, Inc., AECOM, DRHorton, Jones Lang LaSalle Incorporated, Realogy Holding

Corp./ Realogy Group LLC, Cherry Hill Mortgage Investment Corporation, Howard Hughes Corporation, Vornado Realty Trust/ Realty L.P., Welltower Inc., and Zillow Group, Inc. The two non-real estate business cases were Cigna and the Massachusetts Department of Transportation model to re-develop the Interstate-91 (I-91) viaduct. The two non-real estate business cases were selected because their models were designed to maintain continuous engagement with the customer, and provide stakeholder-oriented outcomes. Like the residential real estate industry, the insurance and infrastructure sectors are capital intensive. Like the building, Cigna's offerings and the I-91 viaduct create different types of value for multiple stakeholder types across the offering life cycle.

A state of practice analysis of the residential real estate industry was assessed from the deconstruction the ten cases. Deconstruction of the Cigna and I-91 viaduct models served as ideation inputs for new business models. New prototypes of outcomes-oriented business models were generated from relevant inputs. The feasibility of insurance and infrastructure practices in the real estate industry context to manufacture outcomes through services, intangible, financial, and physical assets were gauged using the business model reinvention wheel described by Voelpel et al. (2004). With this guidance, the conditions for the success of these business models were observed in terms of the customer/user behavior change potential or new customer value proposition, the potential technological strength or directional gains, the potential profitability, and the potential for value system reconfiguration. Wirtz & Daiser (2018) exemplified Voelpel et al. (2004) for BM feasibility assessment. This assessment included outlining key business environment assumptions, including technological requirements, identifying essential resources and processes, examining critical interdependencies, and evaluating potential internal or external BM alignment to assess the feasibility of a potential BM.

Table 1: Business Model Innovation Process in Building Development

Phase	BMI Process Phases	Process Activities	Research Sub-goal	Method
1	Analysis	Analysis of current BM components, the customers, and the competition	Study the state of practice of residential real estate business model (e.g., stakeholder roles, business objectives, value flow in the market, competitive drivers, current profit formula)	Content analysis of ten real estate industry business models
2	Ideation	Define the BMI objective and understanding the customer needs	Study business model from non real estate business cases	Content analysis of Cigna and I-91 viaduct development business model
3	Feasibility	Discern the intricacies of the business environment and alignment requirements	A methodical assessment of the feasibility of new business models	
4	Prototyping	Model and analyze BMI design alternatives	Design new profit formula and innovate BM components by combining new customer value proposition (e.g., building outcomes and values from building qualitative portion of mixed methods study)	Analogical reasoning to combine business model to design new profit formula and innovate BM components
5	Decision-making	Evaluate the harmonization of BM components in BMI design alternatives, and test designs	Discussion of each BMI design	
6	Implementation	Develop and execute step-by-step plan to realize new business models	Future research opportunity	
7	Sustainability	Monitor business outcomes, cultivate/sustain organization-wide learning, protect long-term competitive advantage		

4.4 Validity of Research Methods

The procedures in Creswell (2014), Creswell & Miller (2000), Creswell & Plano Clark (2011) determined the validity of the qualitative studies (i.e., the systems view of building performance study, the first portion of the mixed-methods study, and the business model innovation study). A rich, thick description of the findings and data source triangulation were the strategies employed to strengthen the validity of the systems view of building performance study. The validity of the qualitative portion of the mixed methods study was due to data source triangulation from 1,561 documents, peer debrief of the knowledge management scheme, and use of the rigorous and accepted LDA topic modelling method. Also, the means-end theory was a well-established concept to provide a rigorous foundation for a knowledge management scheme. Sensitivity analyses on key CBA model assumptions were conducted to assess the impact of uncertainty on NPV results. The business model innovation research validity was supported by a peer debrief after each case, and the rich, thick descriptions of findings. Lastly, the potential influence of the researcher's bias on each study is subsequently discussed in section 4.5 as an additional validation measure.

To minimize potential threats to correct or accurate assessments from the integrated mixed-methods data: 1) the qualitative building outcomes and values were direct inputs to create the CBA and were recorded in the impact inventory, 2) the quantitative feature was designed using systematic procedures, 3) hypothetical scenarios were generated to test the CBA tool. These steps were in response to the following risks of invalid exploratory sequential mixed methods research: 1) creating the quantitative feature independently of the qualitative results, 2) not developing rigorous quantitative features, and 3) repeating data samples from the qualitative study to test the quantitative feature (Creswell & Plano Clark, 2011).

4.5 Researcher Reflexivity

In all academic studies there is the potential for bias as researchers inevitably draw upon their background and lived experiences to frame, carry-out and interpret analyses on any given topic. In this work, the researcher brings the perspective of an engineering background, specialization in thermal systems, and lived experiences as an African American homeowner and previous renter. The key to overcoming biases in research however is to acknowledge their potential sources, and to take steps to ensure objectivity, often through the collection of a plurality of viewpoints. Herein, the classification of building system agents in section 5.1.3 may have been shaped by the researchers engineering background, but was also consciously informed through broad explorations of engineering, management, and social science literature that ultimately connect agents to functions and performance criteria that span functional, social, and emotional implications of design decisions. Similarly, while the researcher's thermal system knowledge shaped some aspects of the mixed-methods study, particularly the attention given to building energy systems, the qualitative research protocol in Appendix F was designed with another researcher of an unrelated academic background and contained information from a protocol applied in a separate context to minimize the corpus bias and develop insights on a broad array building outcomes and value drivers. Lastly, in recognition that the researcher's direct experiences with renting and home ownership could influence the impacts accounted for in the quantitative portion of the mixed-methods study, costs and benefits examined were drawn directly from the building outcomes identified in the qualitative study and were quantified using data from multiple sources to ensure that the resulting quantitative model is robust and transferable to a wide array of building and housing scenarios.

5. A ROBUST, INTEGRATED VIEW OF PERFORMANCE-ORIENTED BUILDING DESIGN

Chapters 3 and 4 illustrated that the current building design philosophy fails to capture the diverse set of factors or outcomes that constitute building performance resulting in building performance variability and missed performance targets. To expand the current modular building design paradigm, a stakeholder-oriented, integrated systems view of building performance was established to shape the holistic picture for equitable, effective, and sustainable residential buildings as described in detail below.

To begin, an appreciation for the building as a complex, socio-technical system is chartered to understand how well building subsystems are designed for system-level performance currently, and to outline potential innovation opportunities to close the human-building interaction and building performance gap. This systems view of building performance and design gap identification was adapted from Lumpkin et al. (2020) (see Footnote 1). It introduces building system behavior consequent from occupancy and value codification, derived from building system agent classification given existing definitions of building system functions. The intentional study of building subsystem synergies, and building characterization as an open, complex, socio-technical system enables a conceptualization of a systems view of buildings as a profile of building subsystem influence on system-level (e.g., functional, social, and emotional) metrics.

The systems view of building performance highlighted that the current building design paradigm does not capture the non-linear interaction produced by building agent synergies occurring from occupancy; nor the notion that a building's purpose drives its performance. The first half of the mixed methods study creates an inventory of the critical sociotechnical, spatio-temporal variables that influence building performance, as observed in the literature. The topic modelling results highlight that different schools of thought on building performance exist, are connected, and that different variables inform each school. These same results identified the environmental variables affecting buildings such as stakeholders, and their circumstances. Therefore, the building purpose varies with each stakeholder, and stakeholders change over time bearing differing contexts. The existing paradigm studies how building design factors influence occupant behavior and how occupant behavior influences building performance. Use of the means-end model enables expansion of the existing paradigm into an integrated, stakeholder-oriented view of building performance; one that includes stakeholders, their use contexts and sought purpose. The building effects on stakeholders segmented stakeholder's sought purpose in terms of outcomes and values (i.e., user-centered, impact-focused metrics). Consequently, these critical variables are organized to create an impact model that may serve as a building performance knowledge management scheme. This stakeholder-oriented view of building impacts enables redefining the building purpose to include effects and impacts in addition to existing functional goals and technical metrics. Also, this view accounts for stakeholders and their characteristics. The collective interpretation of this information may allow for building codes to account for building effects and measure effectiveness.

The outcomes and values identified in the qualitative phase of the mixed-methods study are the tangible and intangible building effects on stakeholders resulting from building use. A stakeholder gain or loss due to building use yields a net benefit of the building. Recall, the building value is the net benefit a stakeholder can receive from building design improvements. Also recall, this research was motivated to disentangle, frame, and resolve the longitudinal misalignment of the building value between key stakeholders. Therefore, a multi-stakeholder, longitudinal building value model quantifies the net benefit of the building for different stakeholders over time for potential alignment. This model captures the financial implications of building design choices on downstream stakeholders, the diffusion of longitudinal building value for direct and indirect stakeholders, and stakeholder contextual changes. This model reveals potentially monetizable opportunities for improved building outcomes (i.e., building benefits). In summary, the work presented in Chapter 5 affirms Hypothesis 1, and provides mechanisms for targeted, whole-building innovation.

5.1 Systems-view of Building Performance

Understanding the building as a complex system

The building is an open system because the amount of building energy consumed varies with different initial conditions in different ways. It is also considered open because the building energy systems interact with other systems in their environment, and their parts are under continuous exchange of matter with the environment (Von Bertalanffy, 1968). This exchange can be importing, exporting, breaking up, or breaking down material components (Von Bertalanffy, 1968). The building continuously exchanges matter with the outdoor environment and the occupant, as shown in Figure C7. On this note, the system's environment includes uncontrollable factors that affect the properties and performance of the system. Transactional environmental factors are those that the system can influence but not control (Ackoff, 1999). For example, occupant activity and decisions (e.g., water flow activities) are transactional environmental parts of the building ecosystem. Contextual factors of the environment are those for which the system has no influence or control (Ackoff, 1999), such as the outdoor air conditions, the outdoor environment, and the outdoor environment's impact on the building envelope. The system (building) environment is not to be confused with the built environment.

In buildings, people in the system use natural and artificial sensory information to make decisions. The output of each agent is created due to the human and technical interaction between the parts. For a system's optimal performance and utility, human and technical aspects must be jointly optimized (Bauer & Herder, 2009). Establishing the building as a socio-technical system and designing it requires consideration of human and technical factors that influence the functionality and usage of the building. A socio-technical approach to system development leads to more acceptable systems to end-users and delivers better value to stakeholders (Baxter & Sommerville, 2010).

The building is a complex system because the agents are interrelated, inseparable from the environment, time-dependent, adapt in various settings, and can spontaneously arrange interactions purposefully without the help of an external force (Castellani & Hafferty, 2009). Complex systems differ from rules-based, mechanistic systems (e.g., simple and complicated systems) in that these systems have "multiple interacting components, such that the overall behavior cannot be inferred merely from the behavior of the components, but emerges from the interaction of its components and the interaction between it and its environment" (Xiong, 2011). Framing the building as an open, complex, socio-technical system can guide whole-building performance improvements and innovation. The application of complex system principles in Table 2 provides insight into the influence of the dynamics of the building component on building performance and potential opportunities to address system-level gaps. Building component functions are inherently connected to the system's environment, each other and continuously adjust to maintain set building goals. Their collective interaction produces a resultant, aggregate, non-linear behavior. This behavior has properties that the individual building components do not have, is pattern-forming, and time-dependent. The most noticeable gap to be resolved in building performance is characterizing this resultant behavior in terms of its properties, patterns, inputs, and influences. A less pronounced gap is in understanding if the current building performance metrics accurately reflect the building goal because the building performance metrics set the component operation; if the metrics do not reflect the building goals, then the component operation will not achieve the building goals. Moreover, as a socio-technical system, its dynamics and performance are characteristically social and technical. Thus, building models should be able to theorize the anticipated socio-technical interactions (e.g., the social role of physical energy) and provide clarity on how the physical/technical factors of physical energy (and the related technologies/materials) interact with the states of people in a social context (Love & Cooper, 2015). It is also crucial to capture the spatio-temporal dynamics associated with energy use and its connection in initial design decisions (Love & Cooper, 2015). Research into new socio-technical variables of interest and performance outcomes (e.g., energy consumption) needs to be derived from a systematic, integrated approach using socio-technical theory, hypotheses, and analyses (Love & Cooper, 2015).

Table 2: Application of systems principles to guide building performance improvements

Principle	Definition	Building Performance Metrics Requirements
Function	The purpose of the system	The goals set for the system drive its performance
Agent-based	The system parts are rule-following and interrelated	Building components follow set standards and are connected to function
Emergent	The system behavior is the result of the collective, complex interactions of the agents of which it is comprised” (Castellani et al., 2009, p. 124)	The resulting aggregate building behavior has properties that the individual building components alone do not have
Non-linearity	The system does not satisfy the superposition principle. The superposition principle means the net response produced by two or more stimuli is the sum of each stimulus output.	The resulting aggregate building behavior is not simply the sum of building component outputs
Openness	Constant, inseparable interaction with the environment.	The inputs and outputs of building components are dependent on the building environment
Dynamics Principle	The system behavior is time-dependent	The resulting aggregate building behavior is time-dependent
Self-adaptation principle	The agents learn through interaction. Holistically, for the system “to survive in various environments, it adjusts to internal and external threats or changes through its methods of self-communication or feedback” (Castellani et al., 2009, p. 124).	Building components monitor conditions and make functional adjustments to maintain system (building) goals.
Self-organization principle	Ability to spontaneously arrange the interactions in a purposeful, particular manner, under appropriate conditions, without the help of an external force	The resulting aggregate building behavior from building component interactions forms a pattern if external influences do not directly intervene.

The systems construct of the building permits insight into the complex building behavior by providing a vehicle to identify counter-intuitive synergies that affect building performance through the technical and non-technical impacts on occupants. For example, the complexity of the building energy demand from a physical perspective is illustrated in Figure C7. This emergent behavior creates the disconnect between the predicted/designed and actual building energy consumption. The emergent behavior is the result of the dynamic interaction between the physical environmental factors (e.g., fenestration, internal loads, mechanical systems, water flow mechanisms, and air movement mechanisms) and personal factors (e.g., human thermoregulation) leading to the necessary expansion of physical design variables into their integrated, meaningful capacity as introduced by this work in subsequent sections below.

Definition of the building system functions

A system is designed to achieve a purpose and consists of two or more essential parts (Ackoff & Gharajedaghi, 1996). The purpose of sustainable buildings as defined by the USGBC and the High-Performance Building Council was mentioned previously. According to the U.S. Environmental Protection Agency, the purpose of sustainable buildings is to provide a healthy, resource-efficient built environment (US EPA, n.d.). The EPA definition is assumed to be the primary building function. The Whole Building Design Guide (WBDG) design functions for HPBs are listed below and can be viewed as the functions of a building.

The Whole Building Design Guide design functions (WBDG, 2018):

> “Cost-effective: Pertains to selecting building elements from life-cycle costs (weighing options during concepts, design development, and value engineering) as well as necessary cost estimating and budget control.
>
> Safety and Security: Pertains to the physical protection of occupants and assets from unnatural and natural hazards.
>
> Sustainability: Pertains to the environmental performance of building elements and strategies.
>
> Accessibility: Pertains to building elements, heights, and clearances are implemented to address the specific needs of individuals with disabilities.

> Functionality: Pertains to functional programming—spatial needs and requirements, system performance, durability, and efficient maintenance of building elements.
>
> Productivity: Pertains to occupants' well-being—physical and psychological comfort—including building elements such as air distribution, lighting, workspaces, systems, and technology.
>
> Historic Preservation: Pertains to specific actions within a historic district or affecting a historic building whereby building elements and strategies are classifiable into one of the four approaches: preservation, rehabilitation, restoration, or reconstruction.
>
> Aesthetics: Pertains to the physical appearance and image of building elements and spaces as well as the integrated design process."

Classification of building system agents

The agents are defined by their role in helping the building achieve its purpose (Jennings, 2000) and are listed in Table 3. Agents were classified and generalized to make links between traditional and desired performance functions. The described classification was employed in this research to view building systems as designed agents to meet sustainable building performance functions. These classifications simplify the numerous 'systems' in buildings to analyze the pairwise connections and outcomes. This list was not comprehensive; however, many traditional building systems fit into one of these categories.

Table 3: Generalized building agents

Desired performance function	**Building agents**
Manage the indoor air humidity and temperature	Controllable heating/cooling system
Remove the indoor pollutants	Contaminant removal system
Supply light indoors	Controllable lighting system
Protect against fires	Internal hazard system
Separate the physical indoor space from the outdoor physical environment, load support, control energy and mass flow (e.g., building envelope)	Structural system
Allow occupants to enter and exit the building	System of ingress and egress
Distribute and collect water	Water system
Supply energy for agent/building operations	Energy sources
Regulate noise	Acoustical optimization system
Control the building use, release energy and contaminants indoors	Occupants
Communicate information across building systems	Communication networks
Contain or manipulate a mass using thermal energy for meal preparation	Cooking appliances
Contain or manipulate a mass using water and energy to meet human needs	Water and energy appliances
Contain or manipulate a mass using energy to meet human needs	Energy only appliances
Control of many small integrated electrical parts to meet human needs	Electronics
Consume energy for business contexts	Context-specific energy consuming equipment
Make space suitable for living or working	Furnishings and finishings
Create the look and feel of a space, spatial configuration, location, amenities, floor plan	Space layout
Attach to the external walls of the building structure	External attachments

Codification of the emergent, non-linear building behavior

The way each essential part (agent) of a system affects system functionality depends on the behavior or properties of another essential part of the system (Ackoff, 1999). The interactions between agents were assessed by systematically examining their pairwise relationships using the logic shown in Figure 3. The emergent building behavior was evident by the unintentional synergies that influence the agent in achieving its designated functions. Examining the pairwise relationships, the resulting outcomes, and the extent to which synergies and building impacts are addressed in modern building design disaggregate the emergent behavior and design gaps. The study investigated if relationships were concretely captured through physical or empirical relationships, and if not, the extent it has been investigated in the literature. In the latter case, the literature of the relationship may or may not have been previously studied, and if they have been, was a relationship indicated. Figure 4 is a summary of this analysis in matrix form, and the relationship status was recorded as [row, column] (e.g. [R1, C1]) throughout the discussion.

The matrix in Figure 4 conceptually employed transduction principles, potentially connecting physical parameters to the form in which it impacts. In Figure 4, the black box indicates redundancy. The pairwise relationships can be structured to equate to an outcome because it is the summation of agent functions that create building performance (e.g., outcomes). This work does not break down the synergistic outcomes into design parameters. Still, the agents involved in the synergy could be decoupled and potentially connected to design parameters if they are known. To illustrate this concept, the controllable heating and cooling, contaminant removal, and controllable lighting relationships are assessed. These agents were selected because space heating and cooling, ventilation, and lighting constituted 54% of the U.S. energy demand in commercial buildings (the U.S. EIA, 2012). Space heating and cooling demanded 51% of the site energy consumed in U.S. homes (U.S. EIA, 2018).

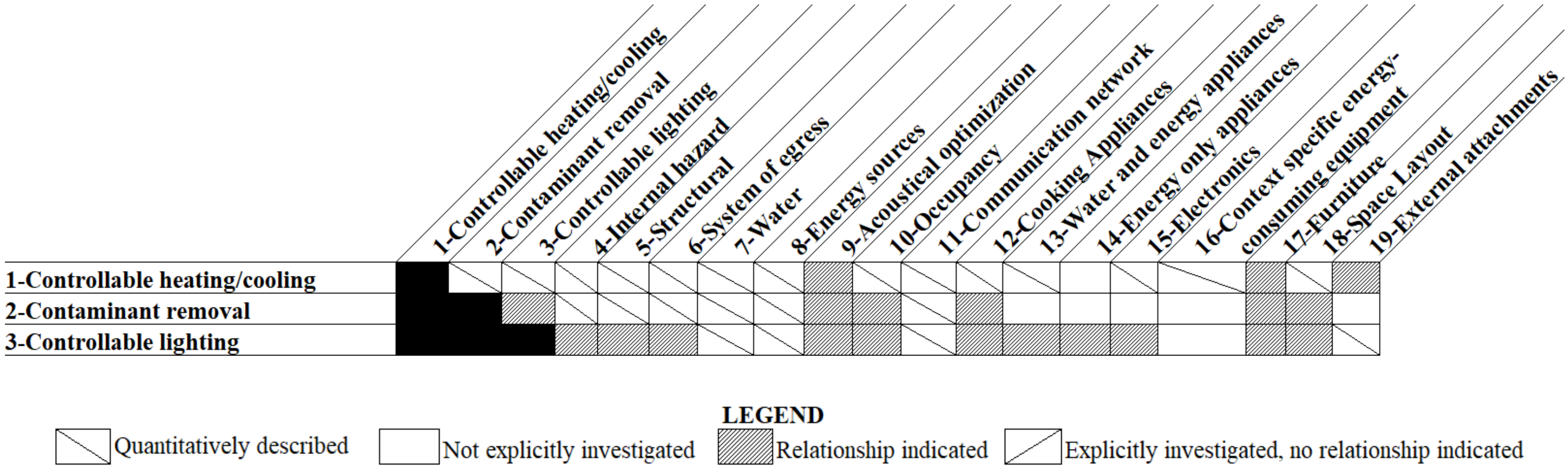


Figure 4: Example matrix used to analyze agent to agent relationships

Recall, the design goal for the space conditioning system is to provide a system that maintains a comfortable and healthy internal environment for the building occupants (Mitchell & Braun, 2013). Air temperature and humidity control design liveable, comfortable indoor air conditions that prevent building degradation. ASHRAE Standard 55 is the U.S. model for thermal comfort (Eddy et al., 2017). Ideally, it is employed to ensure that 80% of building occupants are thermally satisfied. Mechanical ventilation air is used to maintain indoor air quality using ANSI/ASHRAE Standard 62.1 (Berlin et al., 2016). The heating, ventilation, and air-conditioning system is segmented into two agents – the controllable heating and cooling system and the contaminant removal system - as these are the primary roles of the HVAC system. A change in thermal state in space changes the perceived indoor air quality (Al Horr et al., 2016). The relationship between temperature and humidity control with indoor air quality is apparent, but many buildings fall short of optimizing this synergy (Huizenga et al., 2006).

The emergent behavior of the controllable space heating and cooling agents is highlighted by its counterintuitive synergies. The agent synergies influence agent-related design goals and often impact the occupant, revealing improved equipment and building agent design opportunities. Designing the equipment and building agents without accounting for their interdependence on other systems in the building context drives performance gaps today. It provides opportunities for future improvement to design processes, as outlined below. As a reminder, the relationship position noted in the matrix is indicated as [row, column] (e.g. [R1, C1]).

There are synergies with other building parts that influence the thermal control system's ability to achieve its intended functions. Fanger's model in ASHRAE Standard 55 assumes thermal comfort is influenced by six primary factors: the human metabolic rate as a function of the task, clothing (insulation), air temperature, air speed, radiant temperature, and humidity. This Standard neglects the impact of a counter-intuitive synergy between thermal comfort and exterior attachments. As reported in one study, "Shading systems significantly improved the operative temperature and radiant temperature asymmetry during cold sunny days" (Bessoudo et al., 2010, p. 1). Similarly, Tzempelikos et al. (2010) determined that irrespective of the glazing type, shading enhanced thermal comfort conditions by reducing extremes in operative temperature and radiant temperature asymmetry [R1, C19]. Beyond shading, the use of water systems and cooking can influence occupant thermal comfort. There are moisture sources (Hens, 2012), and moist air is perceived as uncomfortable due to its potential to facilitate latent heat loss. Low relative humidity can induce electric charges, creating further occupant discomfort. Relative humidity also affects a human's perception of fresh air. Dryer, cooler air is perceived as fresher than warm and humid air, highlighting an essential link between thermal control, moisture, and IEQ. Although thermal impacts from solar radiation and artificial lighting are quantitatively captured from an energy perspective, the intangible effects of lighting on IEQ represent another agent-to-agent synergy that is not quantitatively evaluated.

Regarding energy efficiency, the thermal load on the HVAC system is calculated using the heat balance method (ASHRAE, 2013) [R1, C2:3], [R1, C5:8], [R1,C10], [R1,C12:17], [R2, C8]. This method considers the effect of outdoor weather, internal heat sources, and indoor set-points on the thermal load. However, the uncertainties associated with these factors are neglected in design which can cause significant variance in the peak cooling load (Gang et al., 2015). This oversight would result in an oversized system. An oversized system yields higher initial costs, lowers the system energy efficiency, increases utility costs, and possibly reduces thermal comfort. The conventional heat balance method also neglects the counter-intuitive thermal load relationship with the space layout and furniture. Raftery et al. (2014) studied the impact that furniture and contents (e.g., internal mass) have on zone peak cooling loads using a perimeter zone model in EnergyPlus with the zone parameters of the HVAC system type (overhead, underfloor, and thermally activated building system (TABS)), orientation, window to wall ratio, and building envelope mass. The internal mass parameters were the amount, area, and material type. Their results highlighted that adding internal mass changed the peak cooling load by a median value of −2.28% (−5.45%, −0.67% were the lower and upper quartiles, respectively). The thickness of the internal mass surface meaningfully affected the peak cooling load, where thinner surfaces increased the peak cooling loads. Raftery et al. (2014) also noted the low amount of accurate recommended values for internal mass models available. The authors suggested that the quantity, distribution, and average aggregate thickness, and material type of furnishings be explored in future buildings research. Although thermal gains through the building envelope are considered in the heat balance method, this method does not fully capture the synergy between the heating and cooling system and the building envelope [R1, C18]. It is known that from an energy perspective, free sunlight, thermal mass, insulation, shading, reflective surfaces, and natural ventilation can be used to reduce cooling loads in the summer (IEA, 2013); however, optimizing this synergy is not common practice. Seasonal optimization of the heat flow from solar radiation is a challenge, and related technologies are costly (IEA, 2013). Moreover, these synergies are captured in the development stages only if early decision-makers pursue the benefit of spending additional time in advanced building envelope design. These findings show the opportunities present to reduce the cost or technical barriers to building envelope and thermal control system synergy realization, so early decision-makers are influenced to and can easily capture them.

Thermal comfort is also connected to energy efficiency. For example, Shahzad et al. (2017) examined office layouts with high and low levels of thermal control. Their analysis indicated that a balance between thermal comfort, energy efficiency, space layout, and occupant control is required, and user satisfaction, user comfort, and energy consumption were considerably higher in the traditional cellular office with a high level of control compared to the low-level control, contemporary open-plan office. There is a significant amount of research to intelligently control energy and comfort management in sustainable buildings extending the synergy to the communication network, contaminant removal agent, lighting, appliances, and the energy source [R1, C11]. Occupant behavior, activities, and preferences are feedback sources for effective building automation (Shaikh et al., 2013). Building integration with energy sources (e.g., renewable micro-grid resources and utility grid supply) needs further research (Shaikh et al., 2013). Smart appliances, integration of safety, security, and monitoring are upcoming factors that should remain in building automation systems (Shaikh et al., 2013).

The thermal control system also impacts other performance metrics not captured during the design process. The impact of the heating and cooling agent on occupant's productivity (in terms of human performance) is not a direct design metric. However, the delivered air volume at the desired temperature and humidity has a relationship with sound. The air temperature, sound, and ventilation rate are an environmental synergy that can affect mental workload and cognitive fatigue. According to Varjo et al. (2015):

> "The combination of high intelligibility of irrelevant speech, high room temperature, and low ventilation rate impairs the perceived working conditions and occupant cognitive performance. It is possible to suggest that by designing acoustic room conditions, thermal conditions, and ventilation rate adequately, satisfaction with the work environment is increased, somatic symptoms are decreased, and the possible impairments of work performance can be avoided. Based on subjective assessments, mental workload, cognitive fatigue, and symptoms have shown to be higher and environmental satisfaction lower in environments with higher room temperatures (29°C), highly intelligible speech (low absorption and high sound masking level), and negligible fresh air supply rate (2 l/s per person)."

A temperature change can have the same effect on productivity as a change in sound level. The neutral sound pressure of a typical air-conditioned office is between 45 dB and 70 dB. A 1°C temperature change has the same effect on productivity as a change in the noise of 2.6 dB (Al Horr et al., 2016). A specified room noise criterion must often be demonstratively met within precise limits during building commissioning. Procedures to demonstrate compliance vary in effectiveness due to significant point-to-point sound pressure level variation (ASHRAE, 2013). The 2013 ASHRAE Handbook did not have a general agreement on an acoustical measurement procedure for commissioning HVAC systems. AHRI Standard 885 incorporated a suggested procedure for field verification of NC/RC levels (ASHRAE, 2013) [R1, C9].

The controllable heating and cooling systems also have inadvertent health impacts. Poor acoustical optimization of HVAC systems can impact sleep quality (Öhrström & Skånberg, 2004) and increase stress levels at work (Al Horr et al., 2016), especially in aggregate with context-specific energy-consuming equipment (e.g., telephones). From a thermal perspective, heating systems that rely on wood or coal can lead to serious health effects such as respiratory and cardiovascular mortality and morbidity, as carcinogenic compounds can be emitted (Euro.who.int, 2019).

Improper management of the heat, moisture, and airflow through the building envelope may impact the building's functionality, aesthetics, and occupant health. For example:

> "This may cause electrochemical corrosion of metal components, the chemical deterioration and dissolution of materials such as gypsum sheathing, ceiling tiles, especially wood products on the exterior wall, discoloration of building finishes, volume changes (swelling, warping, and shrinkage) that can cause degradation of appearance, structural failure, cracking, freeze-thaw deterioration of concrete, stone, and masonry, especially for buildings in cold areas if the building materials contain moisture, the increase of material thermal conductivity due to the moisture within the material, the growth of biological forms, including molds, mildews, mites, etc." (Zhong, 2008, p. 1)

Building-level hygrothermal analysis and the impacts on building durability, thermal comfort, indoor air quality, energy efficiency, and building-related respiratory issues, skin and eye irritation are quantified, and ideally, considered in the conventional design process. Nevertheless, building degradation may cause the building envelope assembly to fail as a sound barrier for traffic noise which has its own set of health issues not considered in the conventional design process. Also, building aesthetics play a role in design decisions, and these decisions tie to energy efficiency. For example, highly reflective surface colors in hot climates, especially roofs, reflect significantly more sunlight than alternate colors. The International Energy Agency found "an ordinary gray roof might reflect 20% of sunlight, a red roof 40% and a bright white roof 80%" (IEA, 2013, p.118). However, the intangible benefits of aesthetics are not quantitatively evaluated with energy efficiency.

The International Fire Code addresses potential safety hazards for fuel-fired appliances, emergency, standby power systems, electrical equipment, wiring and hazards, mechanical refrigeration, elevator recall and maintenance, stationary storage battery systems, and commercial kitchen hoods [R1, C4]. However, heating systems that are not appropriately designed can encourage building occupants to take additional measures that are ultimately unsafe. As a result, heating equipment accounted for 15% of the reported home fires in 2011-2015, 19% of home fire deaths, and $1.1B in direct property damage (Campbell, 2017a), affecting the safety and security objective of the internal hazard system. Energy insecurity was another result of sub-optimized HVAC system design as 11% of households keep their home at an unhealthy or unsafe temperature, one in five households reduce or forgo necessities like food and medicine to pay an energy bill, and 14% of households receive an energy service disconnection notice (EIA, 2017).

A healthy indoor environment is maintained with suitable indoor air quality (IAQ) by removing contaminants. The contaminant removal agent is designed to meet health and energy-efficiency design metrics. Appropriate IAQ can reduce the likelihood of sick building syndrome (SBS) and building-related illnesses (BRI) and is accomplished by adding outdoor air into the indoor space, which can be achieved through mechanical and natural ventilation and infiltration. Natural ventilation is accomplished through operable windows and doors. Symptoms of SBS include headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea, difficulty in concentrating, fatigue, and sensitivity to odors. Symptoms of BRI are cough, chest tightness, fever, chills, and muscle aches (U.S. EPA, 1991, p.1). Ventilation also has a well understood direct relationship with energy efficiency. Personalized ventilation can reduce overall energy consumption by 15-30% by supplying fresh air directly to the occupant's breathing zone. The combined effect of personalized ventilation and central air conditioning helps to enhance IAQ acceptability by the occupants (Al Horr et al., 2016). Indoor air quality is typically measured using three methods: ventilation rate, indoor pollutant level, and outdoor air pollutant level (Al Horr et al., 2016). These methods create the contaminant removal system synergy with the communication network enabling feedback to optimize efficiency [R2, C11].

Ventilation also impacts counter-intuitive building performance metrics such as safety and security, other health impacts, and productivity that are not considered in current building design. Regarding safety and security, the structural system and ventilation have a clear empirical relationship with fire development and control [R2, C4:6]. Fenestration systems are structural, can provide natural ventilation, and can be systems of ingress and egress. Doors and windows are ventilation openings in the case of a fire. Ventilation controlled fires and flashover are considered in structural design (Buchanan & Abu, 2017), and means of egress and mechanical ventilation are both considered in fire code design (International Fire Code, 2012). Ventilation also plays a role in noise-related health impacts. Öhrström & Skånberg (2004) participants reported that combined noise "from ventilation and road traffic caused more awakenings, worse sleep quality, and more movement during sleep." Statistically significant increases in human performance in schools and offices have been linked to increased ventilation rates, and the relationship has been quantified (IAQ-SFRB, n.d.). Increased ventilation rates are connected to significantly lower absence rates in offices and schools, providing significant financial benefits (IAQ-SFRB, n.d.). Health outcomes related to increased ventilation rates in homes are mixed. More than half of the studies report one or more statistically significant health benefits of increased ventilation rates over the magnitude of the improvements were varied (IAQ-SFRB, n.d.). Little research exists on the influence of ventilation rates on health outcomes other than asthma and respiratory issues.

Contaminant removal has counter-intuitive synergies with other systems not addressed in design but impacts energy efficiency and health-related design goals. Berlin et al. (2016) set the minimum ventilation rates in breathing zones and exhaust rates for specific occupancy categories (e.g., correctional and educational facilities, food and beverage service, hospitality, and dormitories). Still, this alone is not enough to capture the influences of lighting, acoustics, cooking appliance, furnishings, and the structural system on indoor air quality. Furniture is not a significant source of indoor contaminants, but flooring and cleaning agents, and habits may have health impacts [R2, C10]. Ventilation of cooking equipment is considered in building design and codes; however, there is evidence that meeting the minimum standards is often not enough to achieve the desired indoor air quality. Lighting studies conducted by Sterling & Sterling (1983) showed that an increase in fresh air through mechanical ventilation and improved lighting reduce building-related health complaints and symptoms [R2, C3]. Perceptions of lighting quality, such as perceptions of glare and brightness, improved when lighting changes were accompanied by changes in the composition of ventilation air - more so than when only lighting was changed. The perceptions of air quality improved with more outdoor air ventilation. The environment was perceived as "less stuffy and less hot," and the air was cooler with more air movement. Changes in lighting and changes in the ventilation composition resulted in the same effect on occupants – reducing eye irritation, sleepiness, and improving concentration. Lighting only changes an improved mood and reduced irritability. Changing lighting and the ventilation composition reduced eye irritation, headaches, sleepiness, irritability, and improved mood and concentration. Chemical processes in the space appeared to be accelerated and catalyzed by ultraviolet emissions from modern fluorescent lamps, particularly those intended to simulate outside light, supporting the hypothesis that eye irritation in many offices may be due to the indoor photochemical smog, which is a build-up of photochemical byproducts. This build-up is accelerated when light contains ultraviolet emissions. Ventilation near fixtures may reduce smog [R2, C10]. The contaminant removal agent also has a relationship with the building acoustics [R2, C9]. Factory-built relocatable classrooms are attractive in school facility construction. However, teachers in relocatable classrooms turn off the HVAC equipment due to high noise levels in HVAC systems, leading to inadequate ventilation, poor thermal conditioning, and poor indoor air quality. Elevated carbon dioxide levels and volatile organic compounds, including formaldehyde, are common (Apte et al., 2005). Mechanical ventilation and indoor air quality related to noise, where the better the IAQ, the higher the HVAC system noise levels (Khaleghi et al., 2008). Acoustical treatment can enhance acoustic quality but worsen IAQ depending on the type and location of the treatment (Khaleghi et al., 2008). Sterling & Sterling (1983) also noticed that the introduction of outdoor air to the air supply improved odor perception but not significantly. Khaleghi et al. (2008) found that "natural ventilation systems have unsatisfactory ventilation quality but acceptable noise levels when closed, and satisfactory ventilation quality but excessive noise levels with the windows open even without significant external noise sources." Naturally-ventilated spaces with few furnishings or sound-absorbing materials have higher IAQ (Khaleghi et al., 2008). Mumovic et al. (2009) conducted a series of field measurements in nine secondary schools in England and concluded that it is possible to achieve compliance with acoustic standard Building Bulletin 93 (BB93) in naturally ventilated schools with window openings that meet the minimum supply of fresh air for the classroom in quiet settings with low levels of traffic noise. Standard BB93 describes the minimum performance standards for the acoustics of U.K. school buildings (Daniels & Bodkin, 2015). However, Mumovic et al. (2009) found that “typically window installations provide an insufficient openable area to meet the ventilation requirement. Mechanically ventilated schools did not meet the acoustic requirements of BB93 for internal ambient noise levels indicating that mechanical ventilation does not automatically provide a complete solution.” The mechanical ventilation provided a more consistent external air supply but did so at the expense of occupant control; in some cases, the ventilation requirement was only met by using additional windows. Mechanical and hybrid systems resulted in drafts, indicating that classroom ventilation design can improve further (Mumovic et al., 2009). Also, the contaminant removal agent has a relationship with occupant activity and venue type. Chan et al. (2015) measured ventilation rates and indoor air quality parameters in 21 visits to California grocery, furniture/hardware, and apparel stores. Chan et al. (2015) found that “ventilation rates exceeded the minimum requirement of California’s Title 24 Standard in all but one store; however, formaldehyde and acetaldehyde concentrations exceeded the most stringent chronic health guidelines in many of the sampled stores.” Therefore, ventilation rates would need to be significantly higher than the state minimum requirement to lower indoor concentrations below California’s stringent formaldehyde reference level. Removal strategies must be developed based on occupant activity. For example, grocery stores have higher source strengths of acetaldehyde, likely from baking. Furniture/hardware stores have higher source strengths of formaldehyde because of the merchandise that contains formaldehyde (e.g., composite wood products) [R2, C17]. Source control and more efficient filters may be required in spaces with cooking (Chan et al., 2015) [R2, C12]. Contaminant sources such as restaurant cleaning solutions (e.g., drain cleaners, oven cleaners, soaps, detergents, ammonia as a cleaning agent, and grill cleaning solutions and sprays) can cause skin burns, eye and skin irritations (Youth Worker Safety in Restaurants eTool - Clean-up - Hazardous Chemicals, n.d.). Everyday activities such as cleaning are intended to improve the cleanliness and appearance of indoor surfaces; however, they may increase, immediately and for some time after cleaning, indoor levels of volatile organic compounds and airborne dust (Wolkoff & Schneider, 1998). Wolkoff & Schneider (1998) found that “bathroom cleaner was associated with increased lower respiratory symptoms.” Controlling the contaminant concentration level from the source can be a strategy to minimize the number of indoor contaminants without increasing ventilation rates. Zhuang & Li (2014) and Mendell & Mirer (2007) explored the contaminant removal agent's relationship with furnishings. Zhuang et al. (2014) simulated twelve common office situations of varying furniture layouts with different ventilation schemes. Zhuang et al. (2014) showed that furniture layout (in this context, the space layout, and furnishings) is an important factor in indoor airflow and temperature fields [R2, C17] [R2, C18]. The air quality in the breathing zone can be significantly improved by adjusting the furniture layout without altering the ventilation system. Mendell & Mirer (2007) observed indoor air quality relationships with flooring, furniture, office cleaning activities, and wall materials. There was an increased prevalence of lower respiratory symptoms associated with older carpets relative to newer ones for flooring. There was also an increased prevalence of upper and lower respiratory symptoms associated with non-carpeted floors. Their findings suggested the reduced prevalence of lower and upper respiratory symptoms may mean that carpet has a protective effect that may diminish over time as it accumulates particles with normal use. It was also observed that older furniture caused an increased prevalence of eye and skin symptoms. Still, there is little correlation between symptoms and different types of office furnishings or surface materials. Less frequently scheduled vacuuming was associated with increased upper respiratory, eye, headache, and skin symptoms. Mendell & Mirer (2007) also noticed an increase in cough, eye symptoms, and fatigue/concentration difficulty associated with masonry exterior walls, connecting the structural agent linked to the contaminant removal agent.

A socio-economic component may also be involved in the relationship between furnishings, cooking appliances, and indoor pollutants. The National Research Council, Division on Earth Life Studies, Board on Toxicology Environmental Health Hazards, & Committee on Indoor Pollutants (2001) suggested that:

> “Residences with controlled ventilation systems, air filtration, proper maintenance, and appropriately working appliances have lower concentrations of indoor pollutants. This implies that middle and upper socioeconomic groups are at lower risk from indoor pollutants — however, the pollutant source changes with socio-economic status. Low-income housing is more likely to have improper ventilation, poor maintenance, defective appliances (such as improperly operating stoves and space-heaters), and lead-based paint—all of which contribute to higher indoor concentrations of pollutants. Furthermore, people in the low-income groups are more likely to live in mobile homes or apartments, which frequently are crowded (a high ratio of people to volume), resulting in higher concentrations of indoor pollutants.”

However, newer/more carpets, curtains, furniture, and “tighter” building envelopes in upper-income houses are sources of pollution. Also, outside of the occupancy categories and scarce references to mechanical systems (e.g., boilers) mentioned in Berlin et al. (2017), synergies [R2, C13] [R2, C14] [R2, C15] [R2, C16] [R2, C19] have the opportunity for detailed investigation. Berlin et al. (2017) does capture equipment and water synergies such as snow entrainment and rain intrusion and recommendations to resist biological growth. However, the extent to which water activities influence indoor air quality is captured in building design remains elusive [R2, C7].

Building lighting design goals are 1) to ensure occupants have the visual requirements to perform intended tasks in a space (Givler, 2016), 2) to maximize positive human impacts, and 3) to minimize the energy footprint. The latter goal is relevant because the lighting depends on an energy source and contributes to the thermal energy within the space as an internal load. Building light can come from internal artificial sources or external natural sources (e.g., skylights and daylighting).

Lighting impacts system-level goals such as safety and security, accessibility, functionality, and aesthetics. Aesthetics result in the feeling of well-being linked to perceptions of comfort, luxury and plushness were constant with time Boyce (2003). Therefore, the intangible human impacts of lighting quantitative assessment against other lighting metrics. Lighting and electrical systems are synergistic with the internal hazard system affecting the building's safety and security**.** Collectively, these systems were the fourth leading cause of home fires, causing nine percent of home fires and injuries and sixteen percent of home fire deaths (Campbell, 2017b) [R3, C4]. Façade lighting is synergistic with the structural system often used as a means of protection, meeting the safety and security metrics to spot suspicious activity. This relationship is often not captured or quantified. Lighting has a counterintuitive synergy with the system of egress enabling accessibility**.** A high luminance contrast between floor and walls, between walls and door, and between the door and door handle will help people with low vision find a door and open it (Boyce, 2003) [R3, C6]. Lighting is thermally synergistic with the structural system as a source of radiation; lighting systems can affect the surface temperature of interior walls facilitating moisture transfer through the building envelope impacting the building's durability or functionality. Moisture transfer is a synergy between lighting and the water sources available and can affect building functionality. Hens (2012) documented the empirical relationship of moisture transfer due to raised surface temperature depending on the nature of the material through which the flow is occurring [R3, C7]. However, this metric is not directly weighed against other building design metrics. Lighting and the structural system intersect at daylighting as fenestration impacts structural design [R3, C5]. The empirical energy relationship between daylighting through fenestration and its effects on controlling the space air conditions is employed in energy modeling for enhanced efficiency (ASHRAE, 2013) [R3, C5]. The intangible benefits of outdoor views, the passive viewing of natural stimuli through windows can reduce stress, anxiety, the tension of occupants, and elevate the positive mood of occupants, occupant productivity, and well-being (Al Horr et al., 2016). In sustainable building design daylight availability and electric lighting are integrated for reduced energy consumption. The soft benefits of daylighting such as health, well-being, and productivity are not quantitatively evaluated alongside energy efficiency and other costs despite the deep connection to occupant preferences.

Acoustics, mismatches with the energy sources, communication networks, the structural system, occupancy, furnishings and space layout, cooking appliances, electronics, and external attachments influence the lighting agent's ability to promote positive human impacts and energy efficiency. Acoustic and visual comfort are IEQ factors that impact occupant's comfort and productivity [R3, C9]. However, little information is available on modeling how individual environmental conditions influence overall satisfaction with IEQ (Frontczak, & Wargocki, 2011). Balancing acoustical optimization and lighting is essential in theaters. There is often a mismatch between energy sources and lighting needs, impacting energy efficiency [R3, C8]**.** Illumination accounted for 60% of the total global lighting energy consumption and 11% of the total electricity consumption in commercial buildings speaking to a misalignment in energy efficiency [IEA, 2013]. As a direct consumer of electrical energy, lighting represents 15% of the electricity consumption in residential buildings and almost 25% in commercial buildings globally [IEA, 2013]. A similar trend is visible in OECD countries, but in non-OECD countries, lighting represents as much as 45% of the building electricity consumption. Lighting conditions affect both visual performance and visual comfort resulting in perceived lighting quality being classified by its ability to minimize visual discomfort, enable visual performance, and influence behavior. Lighting promotes visual perception of the environment, impacting psychological and physiological behavior and physical health [R3, C10]. There are psychological and physiological health effects due to lighting. First, exposure to bright light at specific times can cause a phase shift where the circadian rhythm can be advanced or delayed. Second, the perceptual system determines visual comfort/discomfort with an image, reception of messages in the space, and directing attention to objects, all of which can modify an observer's mood and behavior Boyce (2003) [R3, C10]. Physical health effects due to visual discomfort are headaches, fatigue, red, sore, itchy, and watering eyes, and aches and pains associated with poor posture, but lighting may not be the sole culprit. These effects often occur with visual task difficulty, overstimulation, and distracting objects (Boyce, 2003). Due to synergies with the structural system, many well-documented lighting control strategies can be pursued as part of a communication network to optimize daylighting, electric lighting, building envelope characteristics, occupancy, and energy efficiency [R3, C11]. De Bakker et al. (2018) further explored how occupancy variation (e.g., office schedule policy) or job function types in the space influenced lighting energy consumption. Alone, neither aspect of occupancy variation significantly impacted lighting energy consumption. However, with a level of control introduced (e.g., individual control, subgroup control, and room control), job-function mix and the office schedule policy significantly impacted lighting energy consumption. An underlying conclusion was that lighting energy consumption was lowest with individual control independent of office schedule policy and job-function type (De Bakker et al., 2018), resulting in an energy savings potential of 30% with a strict policy and 25% with a loose policy compared to manual lighting. However, the savings gained using lighting control at the individual level may not be more economical than room control for some office cases. Similar individual occupancy patterns would negate the difference in savings between desk and room control (De Bakker et al., 2018).

This argument leads to the discussion of the synergies between furniture and lighting [R3, C17]**.** Firstly, furniture and lighting influence thermal space conditions as radiation from surfaces can affect indoor surface temperature impacting energy efficiency and likely occupant comfort. Furniture arrangements can prevent sunlight from reaching the back of a room, reduce the indoor light level and deteriorate the daylight quantity and quality (Mousavi et al., 2018). Secondly, personally controlled lighting at workstations can provide the end-user with precise control of their ambient lighting system to achieve their task (Rubinstein et al., 2004), coupling furnishings, lighting controls (in this context, lighting and a communication network) and occupant (preferences) to energy-efficiency. The impact of lighting and furnishings on occupants is more than task lighting. Thirdly, décor, furnishings, layout, signage, and lighting constitute the visual environment and the look and feel of a space (Boyce, 2014) [R3, C18]. The visual environment is particularly important, as a monotonous environment can lead to a cognitive breakdown, and excessive object variety can lead to dissatisfaction, confusion, and distress Boyce (2014). This supports the psychosocial value of space where a visual environment (created using furnishings or views) that adopts a naturalistic, bio-inspired design; patterned complexity; reduced monochromatic environments, and an organic layout is interesting and has aesthetic integrity (Heerwagen, 2017). For example, in office spaces, people prefer lighting conditions that are bright, spatially, and temporally interesting. Windows also provide a view-out expressing a variation in environmental conditions that is equally important to daylight. A view-out can come with a loss of privacy. Therefore, people prefer windows that provide visual access without visual exposure. Thus, the view-out must be balanced with the view into the space. Occupants will trade off visual and thermal comfort for daylight Boyce (2003). Visual access to the surrounding environment (high prospect) while also feeling protected and safe (high refuge) is one of our primitive preferences (Heerwagen, 2017). Prospect includes internal and external views through windows or view corridors. For example, interior view corridors feel enhanced with interesting elements at the end of the corridor. Spaces with moderate degrees of complexity, nature coupled with high prospect and refuge are highly preferred characteristics. The refuge preference can be highlighted in window preferences with the potential to survey the surroundings but maintain a sense of privacy. Settings with vertical and horizontal expansiveness subdivided into smaller zones, soft rounded forms, irregular layouts, embellishments, and décor are preferred (Heerwagen, 2017). The context, fashion, and opportunity in which lighting is applied distinguishes the lighting impacts on the human [R3, C10]. The context in which lighting is used can create a positive experience. The fashion in which lighting is applied can capture interest or bring a sense of newness or variety.

Lighting and cooking appliances are two end-uses of energy demand in many buildings and add to the thermal load in the space [R3, C12]. This is a socio-economic synergy that is not captured in the traditional building design process. In lower-income households, lighting and cooking appliances are the primary energy users, and providing modern energies to meet these end uses for the poor-renewable energy nexus is growing (Nussbaumer et al., 2012). On a similar note, lighting, cooking, and the services provided through household appliances ownership (refrigerator, washing machine, and water heater), entertainment and education (radio, TV, computer), and telecommunication are among dimensions of poverty [R3, C13] [R3, C14] [R3, C15]. A person is identified as energy poor if the combination of the deprivations faced exceeds a pre-defined threshold (Nussbaumer et al., 2012). Potentially, task lighting research may be the synergy between context-specific equipment and lighting. However, understanding how equipment type and lighting impact each other has the opportunity for explicit investigation [R3, C16]. Electronics and lighting can be connected through a communication network or occupant preferences and influence energy efficiency [R3, C15]. First, the availability of consumer electronics with voice-control platforms and network capabilities to connect with smart home environmental controls is growing. Smart home environmental control systems can control space lighting, temperature, monitor energy use, or shading and drapery. Second, plug-in lights and electronics are also unregulated building energy uses employed to meet the occupant needs. External attachments can affect the daylighting benefits and the solar radiation exchange with space and may be connected to the communication network to employ shading strategies. Shading strategies and glazing units are designed to admit sunlight in the winter and reflect direct radiation in the summer, depending on the climate. Mousavi et al. (2018) suggested that the impact of different interior design variables (such as surface reflectance, glazing tinting, and internal shading controls) on indoor daylighting performance should be investigated. External attachments affect the amount of sunlight that enters the spacing effect, and the impact on the building energy efficiency can be calculated (ASHRAE, 2013) [R3, C19].

5.2 Integrated View of Performance from Agent Outputs

Summary of findings

The agent synergies described above provide an opportunity for innovation by expanding current design metrics towards system-level outcomes. The controllable heating and control agent is connected to more than indoor air quality related health concerns, thermal comfort, and energy efficiency. It is related to aesthetics, productivity, building safety, energy security, and functionality. Similarly, the space layout, furniture, exterior building attachments, climate, internal heat sources, and indoor set-points have a more significant influence on the agent achieving its design goals than is routinely quantitatively considered in the design. The heat balance method from which the thermal load is typically calculated does not capture the level of uncertainty associated with outdoor weather, internal heat sources, and indoor set-points and neglects the counter-intuitive synergy of the thermal load with the space layout and furniture. The method also creates economic barriers for developers and architects for energy-efficiency optimization within the building envelope. Fanger's model neglects the impact of the counter-intuitive synergy between thermal comfort and external building attachments. Further, the intangible benefits of indoor environmental quality are not quantitatively evaluated with energy consumption. Building fire safety and energy security are also outcomes connected to the occupant compensating behaviors associated with the design of the heating and cooling system, which can result in fires, deaths, and a lower quality of life.

The contaminant removal agent is connected to lighting, acoustics, socio-psychological variables, cooking, furnishings, and the building envelope to maintain acceptable indoor air quality. However, the influence of these agents is not considered simultaneously in the contaminant removal agent design. The contaminant removal system also impacts building performance metrics such as other health factors (non-respiratory and skin health impacts are unaddressed), building safety and security, and occupant productivity which is not currently addressed in building design. The agent-to-agent synergies between lighting, acoustics, cooking, furnishings, and the structural system also influence indoor air quality.

Lighting agents are designed to balance building energy efficiency, aesthetics, productivity, and safety and security aspects. However, counterintuitive synergies with other systems can potentially limit this system from achieving its metrics. Its relationship with the internal hazard system and exterior attachments influences occupant safety and security. The acoustic system and structural system impact its ability to enable productivity. Its ability to indirectly promote productivity through physical and mental health and well-being using aesthetics is influenced by the structural system, socio-psychological variables, furnishings, and space layout. Electronics and communication networks impact energy efficiency. Moreover, communications networks influence energy efficiency and are significantly influenced by occupancy job-function types, the level of control, and office schedule policy. Furniture influences energy efficiency and local environmental conditions along with occupant preferences. Lighting systems also impact building accessibility with the ingress and egress system, function congruently with water sources linked to human activity and known environmental parameters, and occupant socio-economic conditions with appliances and electronics. There are lighting guidelines for designers to enhance the feel of the space, knowing its synergies with the space layout and furnishings to achieve desired aesthetics. Nonetheless, it is more of an art than a science. The intangible productivity, health, and well-being benefits (and costs if unaddressed) are not quantitatively assessed against typical economic lighting design constraints, ease of maintenance, user satisfaction, the estimated time of project completion, or other limiting design factors (Givler, 2016) and (Boyce, 2003).

Overall, it should be possible to design for the range of occupant preferences the types of feelings and behaviors a space conveys with energy efficiency. Several actions could inform this design process. Firstly, synergies that are empirically defined and addressed in contemporary building design can be improved by 1) considering the agent's designed function, impact, and synergies with other agents to assess if there are opportunities to create new solutions that address the connection between agents, potentially curtailing the need for several, separate agents, 2) considering the building-level function/metric an agent impacts and assessing if there are opportunities to create new solutions that maximize desired outcomes to minimize the need for design trade-offs later. Secondly, synergies that have been indicated but not quantified have the potential to be quantified in terms of their (technical and human) performance impacts. Thirdly, synergies that have not been explicitly investigated but have been indicated to offer potential can be investigated in terms of their (technical and human) performance impact in the presence of other agents. Lastly, the study did not reveal any explicitly investigated pairwise interactions that did not indicate a relationship likely due to the interconnectedness of building agents.

The Functional-Social-Emotional (F-S-E) Benefits of Building Agents

This work highlighted the need to expand traditional building design focus to prioritize and explicitly design for multiple human performance dimensions. The previous synergy discussion provided numerous examples of how sustainable building design can be reframed to account for broader impact dimensions and sets the stage for different innovation avenues. These examples are not exhaustive, but the agent-to-agent synergies can continue to be explored to get to the root of system-level dynamics and outcomes.

Green building studies traditionally focus on environmental aspects (e.g., energy consumption, water efficiency, and greenhouse gas emission) coupled with technical solutions. Studies on social and economic aspects of sustainability are comparatively lean despite sources emphasizing their importance (Zuo & Zhao, 2013). The following discussion addresses this gap by connecting the building agents (often employed for functional purposes) with their human impacts, presenting two innovation avenues: 1) the functional-social-emotional (F-S-E) benefits of the primary energy-consuming building equipment shifting the design objective toward an end-user perspective, and 2) the potential to shift to centralized metrics that collectively capture the integrated benefits of agents in a holistic system.

A functional benefit is a task that people seek to accomplish (Anthony et al., 2008) (Candi and Kahn, 2016). An emotional benefit explains the way people want to feel in a given circumstance (Anthony et al., 2008) (Candi & Kahn, 2016). A social benefit characterizes people's interaction with other people and their desired perception by other people (Anthony et al., 2008) (Candi & Khan, 2016). The building agents independently contribute and cohesively fulfill F-S-E benefits. The agents are traditionally designed to achieve functional benefits. These functional benefits cascade into emotional benefits such as an individual's health, productivity, and learning, which are all impacted through the dynamic agent interactions. Furthermore, emotional benefits further cascade into social benefits. This work structured the complexity of potential outputs within an F-S-E framework (Anthony et al., 2008) in Table 4 to further perspectives of building performance from outputs to outcomes. While each agent's functional and emotional benefits emerged quite readily through the research discussed herein, social linkages were notably less apparent.

Table 4: An interpretation of the functional-emotional-social benefits of building equipment

Functional Benefits **Emotional Benefits** **Social Benefits**

Agent	Functional Benefits	Emotional Benefits	Social Benefits
Controllable heating and cooling	• Deliver volumetric flow rate of air at setpoint temperature ad designed humidity conditions • Operate with minimal environmental impacts • Limit respiratory and cardiovascular health impacts • Sustain building envelope functionality • Allow for completion of the task/activity • Eliminate building-related respiratory issues, skin and eye irritation • Supply air to maintain safe thermal conditions • Reduce somatic symptoms • Deliver, distribute, and maintain comfortable air conditions without disruption • Optimize cognitive performance (improve mental workload, reduce cognitive failure and fatigue) • Support occupant mental health	• Induce feelings of comfort, well-being, and productivity	• Enable energy security regardless of socio-economic background • Provide thermal conditions that facilitate the desired social interaction
Contaminant removal	• Remove air contaminants • Minimize the spread of fire • Improve sleep quality • Improve cognitive performance • Maintain or improve occupant ability to occupy the building (e.g., attendance rates) • Reduce perceptions of glare and brightness • Support occupant mental health	• Maintain air conditions that avoid headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors; cough, chest tightness, fever, chills; and muscle aches • Provide a desired level of noise	• Facilitate social activity with clean air independent of socio-economic status • Promote positive socio-psychological interaction.

Table 4 continued

Lighting	• Provide illuminance and spectrum variety • Promote psychological and physiological health • Reduce physical health impacts due to visual discomfort (e.g., poor posture, headaches) • Support occupant mental health	• Enable good vision • Highlight aesthetics that encourage feelings of well-being • Facilitate the desired mood (e.g., alertness, relaxed, liveliness) and purchase behaviors	• Ensure that the lighting promotes the desired interaction between people. • Promote positive socio-psychological interaction.

5.3 Stakeholder-oriented view of building performance

A comprehensive, stakeholder-oriented view to intentionally design for underlying interactions between the humans that use conventional building systems, the resulting performance, and measure building impacts was established. Recall the methodology outlined in Section 4.2.1. First, the mixed methods study topic modelling results highlighted the building performance literature disjunction. Then, stakeholders and influential characteristics (Figures 9 and 10), their respective use contexts, and purposes of building use, and potentially influential building characteristics and attributes created a knowledge management scheme (Figure 7) to conform and connect different bodies of the building literature, research, and practice. Last, an economic approach to quantify the value and distribution of building impacts across multiple stakeholders was evaluated. The different phases of the study are illustrated in Figure 6, and the premise is visualized in Figure 5.

Recall, the following hypotheses were tested in the mixed-methods study:

A. Building performance depends on the social and technical variables of the building stakeholders and environment.
B. Buildings affect the economics, environmental, cultural, and health of people who use or are in proximity to them.
C. The value of buildings is dependent upon the needs and goals of the people (or stakeholders) who use them.

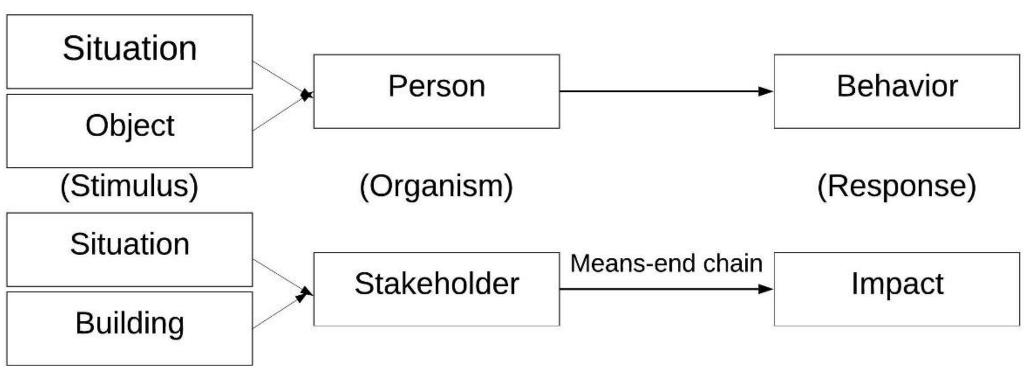


Figure 5: The building use situation (bottom) and the product use situation as adopted from Belk (1975) (top)

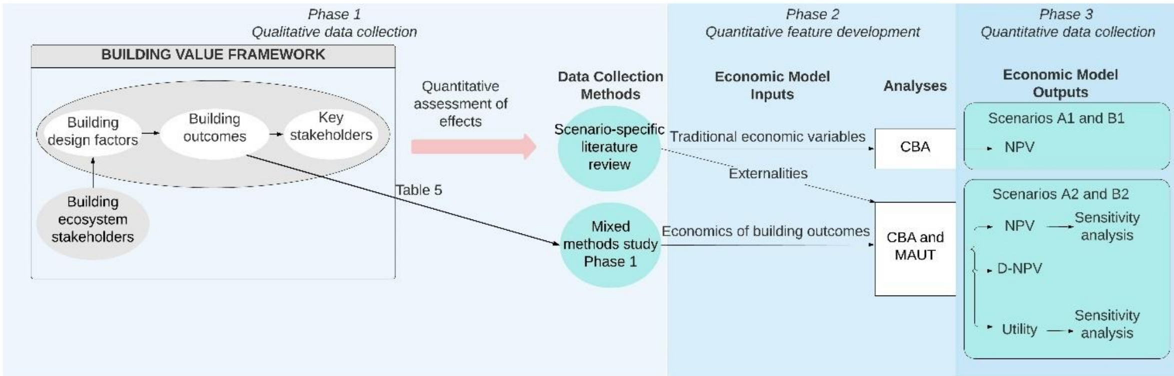


Figure 6: Mixed methods study for building value assessment

The variation of topical emphasis within the building performance literature is shown in the 1) top 50 co-occurring topics 2) the topic dendrogram 3) variation in lexical content seen in Appendix H. The top 10 co-occurring topics in the building performance literature were primarily around housing, and energy efficiency and real estate stemmed from housing creating their own topical nucleus. First, quality of life, public housing, and humans were terms most often discussed with the most occurring topic of housing. Second, sustainability and energy consumption were terms most often addressed with energy efficiency. This segmentation in the literature highlights the human and technical building research divide. The top 50 co-occurring topics in the literature show four perspectives of building performance each expanding from the term "housing" and can be seen in Figure H1. Interestingly, how residences are referred to across clusters exposes the divide in studying different building performance elements. Cluster 1 refers to public housing indicating a societal health perspective; cluster 2 refers to residential buildings showing a clinical, environmental perspective, and real estate in cluster 3 requiring an industrial, economic perspective. Cluster 4 refers to residential property that could indicate a monetary, activity-oriented building classification independent of public interest. Cluster 1 terms were most often addressed with housing and societal demographics such as adult (e.g., age), socio-economic factors, homeless persons, gender, and human experience terms such as health, mental disorder, homelessness. Populations related to government programs (e.g., homeless persons and public housing) are only mentioned in this cluster. Cluster 2 terms are centered around energy efficiency in terms of thermal comfort and energy consumption, suggestive of an occupant's perspective. Cluster 3 is predicated around real estate from 1) commerce terms such as economics, housing supply, market, housing/home prices, 2) geographical classifications such as regional, urban, rural, and United States. This cluster may be connected to a building owner (e.g., investor, home purchaser). Cluster 4 is a nexus of the first 3 clusters. Quality of life is co-occurring with housing, building sustainability is co-occurring with energy efficiency, and residential property and prices connect to real estate. Quality of life is often discussed with prices, environmental health, homeownership, government policy. Building design and sustainability are closer to each other in the cluster and proximity with energy efficiency. In between are societal, individual residential, and contextual terms. Societal terms include social housing, built environment, housing affordability, quality of life, housing policy, and affordable housing. Examples of individual residence terms were performance, indoor environmental quality, satisfaction, and demand. Contextual terms include 1) urban areas (likely to factor in population density or geography), 2) developing countries (likely to describe common human development characteristics between countries), 3) countries such as Italy and Malaysia, which are likely indexes of western Europe and southeast Asia respectively.

The dendrogram Figure H2 highlights that building performance is often discussed in parallel with energy and across two comprehensive bodies of knowledge: 1) socio-economic 2) environmental. The socio-economic literature segments into social and economic building topics. Social topics split into two corresponding pairs of homelessness and public housing; and housing and quality of life. Economic term groups were 1) housing market, prices, and policy, 2) residential property, homeownership, and prices, 3) housing supply and markets, and urban. In the environmental literature, residential buildings' energy consumption, efficiency, and performance are often discussed together; building sustainability and thermal comfort were often addressed together.

Each circle in Figure H3 represents a different topical emphasis of building performance literature. Circle sizes represent the percentage amount of variation in the lexical content of the corpus that each topic captured. For example, topics 7, 8, and 9 each captured greater than 5% but less than 10% of the total lexical content of the corpus and all others topics captured greater than 10% of the total lexical content of the corpus.

Each topic identifies different elements of building performance as explored in the literature. Quadrant I accounted for 38.1% of the total lexical content. The literature in quadrant I was focused on energy consumption. The factors in Topics 1 and 3 described building energy consumption modeling, and use; variables related to structural building physics influential to energy consumption, accounting for 14.5% and 12.3% of the total lexical content, respectively. Depicted in Topic 4 were building mechanical system design variables accounting for 11.3% of the total lexical content. These topics related building energy-related component design to the overall building design and its importance to end use. As it was constituted the most significant portion of the lexical content, it is well addressed in the literature. Also, the terms energy and temperature were generated only in this quadrant, highlighting the importance of different temperatures on building energy consumption.

Two clusters of literature in quadrant II are associated with income generation from an investor perspective. Quadrant II accounted for 36.2% of the total lexical content. The first cluster explicated property valuation and purchase decision variables. Topic 2 depicted financial property characteristics; and financial investment factors were described in Topic 7. Topics 2 and 7 accounted for 12.5% and 8.1% of the total lexical content, respectively. The second cluster highlighted factors associated with measures of productivity. Variables mentioned in Topic 6 could be considered variables related to perceived residential living, such as health, satisfaction, and outcomes. The variables generated in Topic 10 may be regarded as organizational real estate business decision variables such as capital, investment, office, demand, and growth. Topics 6 and 10 accounted for 9.4% and 6.2% of the total lexical content, respectively. This quadrant highlighted building-related business management decisions.

The literature nexus of quadrant III was social from different viewpoints accounting for 17.9% of the total lexical content. Topic 5 was societal housing policies and their connection to individual/household demographics and wealth generation. Individual lifestyle/experiential terms such as work, space, social, plan, design, need, community, user, and people were described in Topic 9. Collectively, the relationship between these topics illustrated building performance is relevant across scales. Topics 5 and 9 accounted for 10.4% and 7.5% of the total lexical content, respectively.

Topic 8 accounted for 7.8% of the total lexical content as the only topic in quadrant IV. The factors generated around topic 8 were around sustainable building development/project management.

Each quadrant highlighted the connection of building performance to its economics. Topics on the left side of the map were connected to direct stakeholder wealth generation for those with stake or equity in the building. Topics on the right side of the map were connected to building cost sources and related in terms of sustainability. The term "income" is almost exclusively in the topics on the far left, except for topic 3. "Building" and "design" juxtaposed "income" from topics 2 and 6 onward to the right on PC1, respectively. "Model" is emphasized in the topics on the top half, contrasted by an emphasis on "need" in the bottom half.

The themes from this study suggest metrics should capture how a building influences an individual's health, economics, culture, and environment. Moreover, these metrics must also be balanced with the exact dimensions of group, organizational, and societal goals. Centralized metrics that collectively capture the integrated benefits of agents in a system are more than the summation of IEQ outputs; they are the immediate effects of those outputs (see Footnote 1).

This work employed systems theory to develop a system-level view of select building system agents (see Footnote 1). Analysis of the range of synergies in the literature between building agents provides a discretized view of each building agent on other agents and their respective contributions to overall building performance. Innovation opportunity areas are grounded in addressing the often-unintentional agent-to-agent performance impacts or impacts on a system's design goals. These relationships have the potential to be exploited by new solutions designed to meet an improved overall performance metric that takes functional, social, and emotional occupant benefits into account. Solutions that do not capture these synergies by design may be limiting the building purpose and, therefore, performance. The proposed knowledge management scheme (see Figure 7) and business models may aid in designing, delivering, evaluating and selecting pragmatic and effective whole building solutions for key stakeholders and the intended building purpose in specific contexts for optimal value.

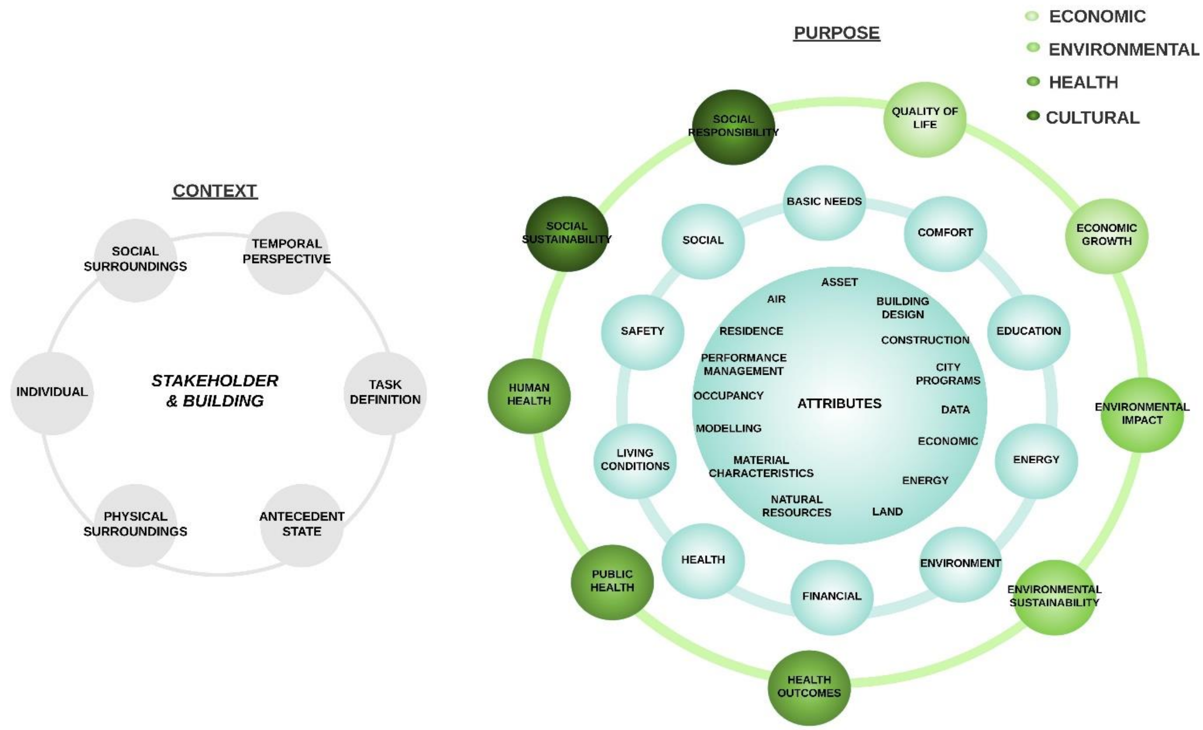


Figure 7: Knowledge Management Scheme of Building Performance

The Building Purpose, Value, and Outcomes

The purpose of a buildings may be derived from the outcomes and value of its use described from meaningful attributes. Hypothesis B is confirmed by evidence of functional and psychosocial consequences of building use. Similarly, Hypothesis C is confirmed by the evidence of stakeholder values associated with building use subsequently discussed.

The attributes of the building that can influence its impact are versatile. Twenty themes to classify concrete attributes and abstract attributes were generated as shown in Figure 8. Concrete attributes are the tangible, and physical characteristics and objective, unidimensional representations that can be directly perceived and directly describe a specific aspect of the product such as size, color, monetary value, and design (Johnson, 1989) (De Sá Brito & Formoso, 2014) (Walker et al., 1987). In contrast, from Johnson (1989), “abstract attributes are the subjective aspects of the product/service that cannot be measured or perceived through the senses but are indirect and personal.” These attributes tend to subsume concrete attributes or are viewed as nested features (Walker et al., 1987). They are evaluative properties relevant to a person and relate the product to relevant consequences (Gutman, 1982) (e.g., style, quality, ease of use, and reputation).

Building attributes that influence its impact can be classified into available natural resources, energy, air, land, building construction, design and modeling capabilities, material characteristics, structure, location, quality, data and performance management capabilities, building services and activities, type, space utilization, and residential factors, economic factors, or asset-specific variables such as occupancy, and city/local programs. For example, factors related to the available natural resources, primary energy sources, including sustainable and renewable sources, energy production, prices, and sources (Anvari-Moghaddam et al., 2015) (Gaglia et al., 2019). Another example is the performance management theme generated from terms related to performance gaps such as control strategies and measures (Manic et al., 2016), system performance, and strategic planning.

These attributes lead to functional and psychosocial outcomes. Functional outcomes are the results of consumption (e.g., time savings); human outcomes may be psychological or physiological (e.g., satisfying hunger or thirst) (Gutman, 1982). From De Sá Brito & Formoso (2014) psychosocial outcomes are “a product's ability to satisfy intrinsic objectives that are symbolic, self-oriented, or other-oriented (e.g., attracting attention, projecting an image aligning with social norms).” From Gutman (1982), psychosocial outcomes may be “psychological (e.g., self-esteem, improved future outlook) or sociological (e.g., enhanced status).” One outcome is **indoor comfort conditions/levels** such as overall user/human comfort, visual comfort, and thermal comfort (Park, 2020) (Liao et al., 2015) (Shah et al., 2019) (Han et al., 2017) (Lan et al., 2019). **Energy-related** outcomes include energy conservation (Gaglia et al., 2019), management (Pereira et al., 2013) (Anvari-Moghaddam et al., 2015), savings/reduction, poverty (Middlemiss et al., 2019) (Nussbaumer et al., 2012) (Hache et al., 2017), needs (Mohareb et al., 2017), data and optimization (Al-Ali et al., 2017) (De Boeck et al., 2015) (Lez-Briones et al., 2018), and demand response (Park, 2020) (Hafeez et al., 2020). Food insecurity (Fafard St-Germain & Tarasuk, 2020) (McIntyre et al., 2016). (Yelowitz, 2017), housing needs (Rohe et al., 2001) (Ultimate & Sitkin, 2020), housing outcomes (Jarbring et al., 2001) (Orr & Peach, 2011) (Fraser & Kick, 2007) (Fischer & Lowe, 2015) (Jacobs et al., 2014), and housing affordability constituted another theme of meeting **basic needs**. Greenhouse gas emissions, sustainable development and operation, and environmental protection (Banday & Aneja, 2019) (Zuo & Zhao, 2013) (Shrubsole et al., 2019) (Yang et al., 2018) (Roper & Beard, 2006) (Lützkendorf & Lorenz, 2005) are **environmental-related** outcomes. Effects on physical, mental, or emotional health and well-being status, problems, or risks (Newman & Holupka, 2017) (Fenelon et al., 2018) (Yanos et al., 2007) (Szabo et al., 2019) (Yeo et al., 2020) are **health**-related outcomes. The building can also have **social-**related outcomes such as social interaction (Johnson, 2013) (Alidoust et al., 2018), cohesion (Andrews et al., 2014), relations (Middlemiss et al., 2019) (Victor & Pikhartova, 2020), mix (Fraser & Kick, 2007) (Vale & Shamsuddin, 2017), and life. Cost savings and financial distress (Boehm & Schlottmann, 2017) are examples of **financial** outcomes. Educational attainment is an **educational** outcome. Another theme was **living conditions** in terms of material or daily living conditions (Andersen, 2008) (Milstead et al., 2006). Crime rates (Lee & Murie, 1999) were categorized as **safety**. It is important to note "resilience" was not a frequently mentioned term but is an important building use measure that can be addressed in each of these outcomes potentially revealing significant research opportunity.

The stakeholder values for consumption are the "centrally held cognitive elements that stimulate motivation for behavioral response" (Gutman, 1982), and can be thought of in terms of instrumental and terminal values. "Human love, family security, responsibility, self-control, helpfulness, logic, obedience, and intellect are examples of instrumental values or the intangible goals related to the behavioral means used to achieve the ends" (De Sá Brito & Formoso, 2014); these are the concrete values of "doing" (Johnson, 1989). Happiness, security, and accomplishment are examples of terminal values - the abstract values of being (Johnson, 1989) or the preferred end-states of existence (Gutman, 1982). Four building impact categories were generated from stakeholder values: economic, environmental, health, and cultural which correspond to the Enabling Innovation Model four areas of significance. Economic stakeholder values include quality of life and economic growth. Environmental values include environmental impacts and sustainability. Health impacts include health outcomes, mental and physical health, and public health. Cultural impacts include social sustainability and responsibility. The values and outcomes are listed by impact categories in Table 5.

Table 5: Values and outcomes of building use

IMPACT CATEGORY	VALUES	OUTCOMES
Economic	Quality of life economic growth	Energy poverty Energy needs Food insecurity Housing affordability Housing outcomes Cost savings Financial distress Living conditions
Environmental	Environmental impact environmental sustainability	Energy conservation Energy savings Demand response Greenhouse gas emissions Sustainable development Environmental protection Crime rates Comfort conditions Daily living
Health	Mental health Public health Human health Physical health	Health status Health problems Health risks Health outcomes
Cultural	Social sustainability Social responsibility	Housing needs Housing outcomes Social interaction Social cohesion Social capital Social life Social relations Social mix Educational attainment

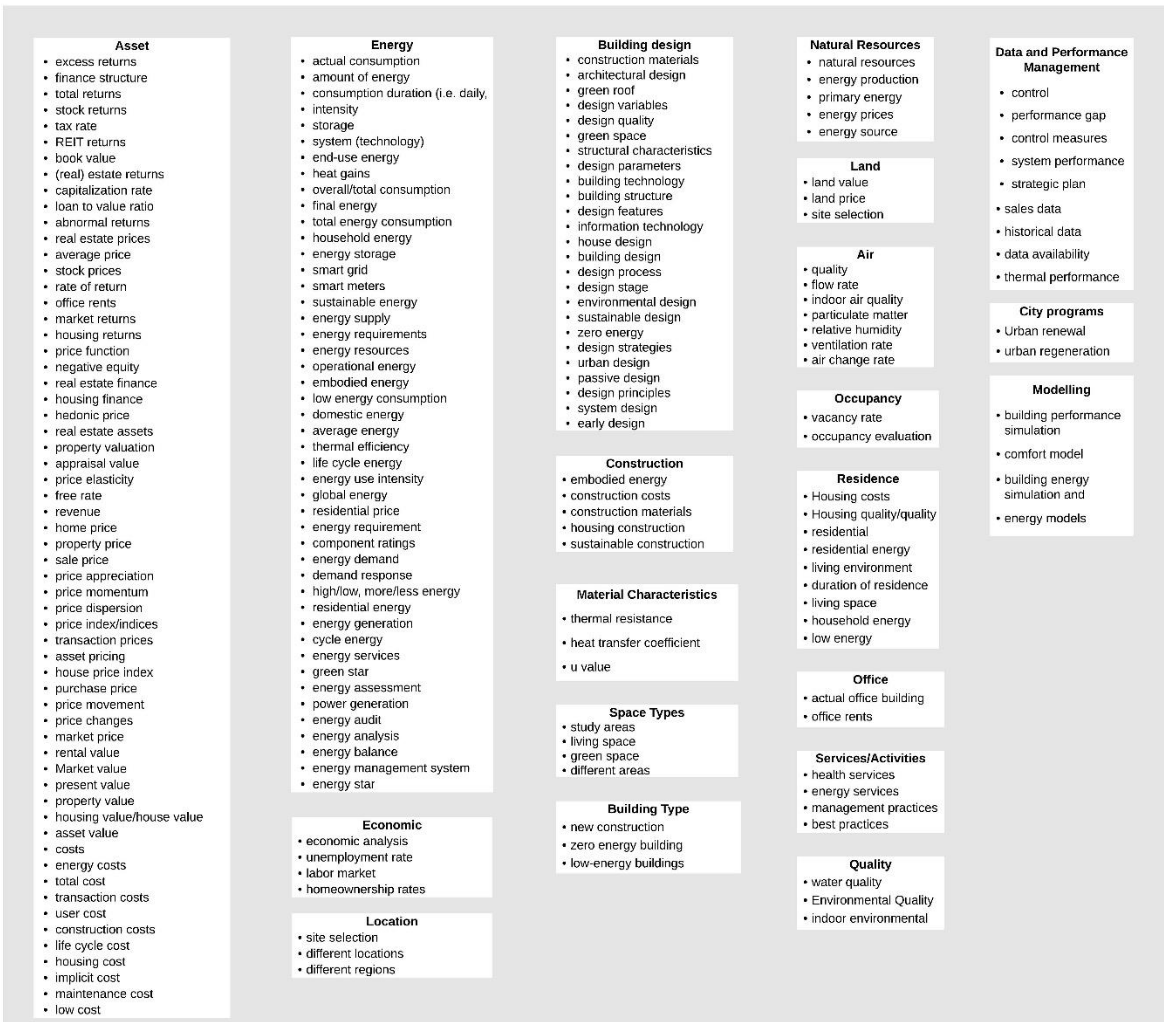


Figure 8: Building system attributes

The Context of Building Use

The stakeholder, their specific characteristics, situational characteristics, and the object itself constitute building engagement. Hypothesis A is confirmed as social and technical variables as context variables alongside building stakeholders were identified as described in this section. Building stakeholders were grouped into sector, industry, market, individual, group, and governing agencies. The building, property, residential building, and social sectors were identified to use buildings. The construction, housing, manufacturing, real estate/REIT industries are interested in engaging with buildings. Also, context could be defined in terms of markets, their respective participants, and related segmentation. Identified markets included commercial real estate, financial (e.g., capital, secondary, and stock), housing, local, labor, mortgage, office, private, rental, real estate/REIT, residential, residential mortgage. Local, central, and federal governments, national institutions like the Environmental Protection Agency, and governing agencies like World Health Organization were identified as stakeholders in the literature. Individuals or groups could be building users, social tenants, or characterized by psychographic (e.g., elderly, homeless) or demographic groups (e.g., age, or socio-economic status). Health organizations, institutional investors, property companies, professional associations - real estate, realtors, green building council, urban economics association, psychological – ethnic associations, and research institutions were organizations generated from the literature. Specific stakeholders like the project team, policymakers, building and property owners, property investors, and the local community also populated. The potential influential characteristics for specific stakeholders were segmented by market, individual/group, institution/organization, government, and into a general segment potentially relevant across other segments depending on the situation. These are listed in Figure 9 and 10. The stakeholder may play a role in the ecosystem or construe a viewpoint (see Figure 9).

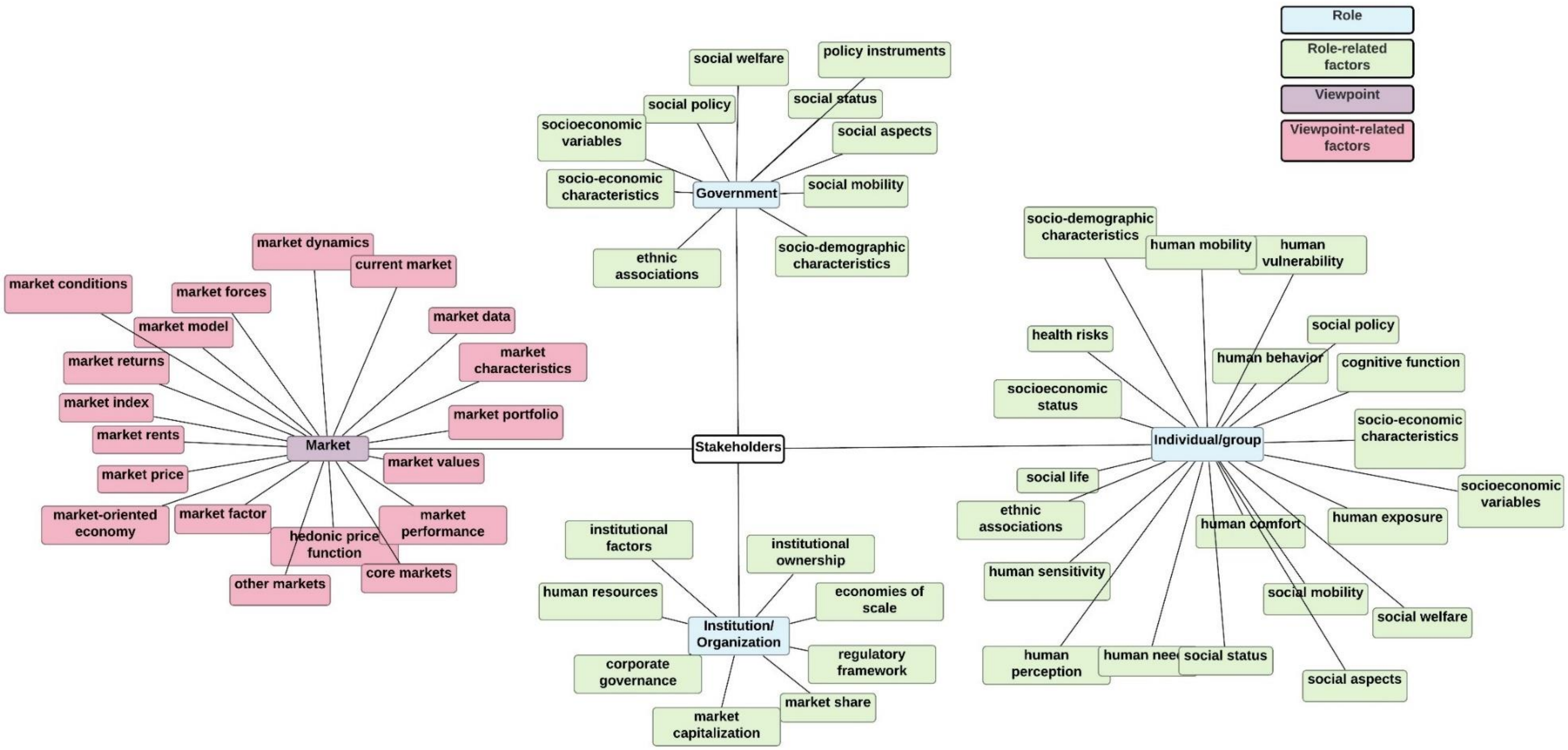


Figure 9: Specific stakeholder ecosystem characteristics

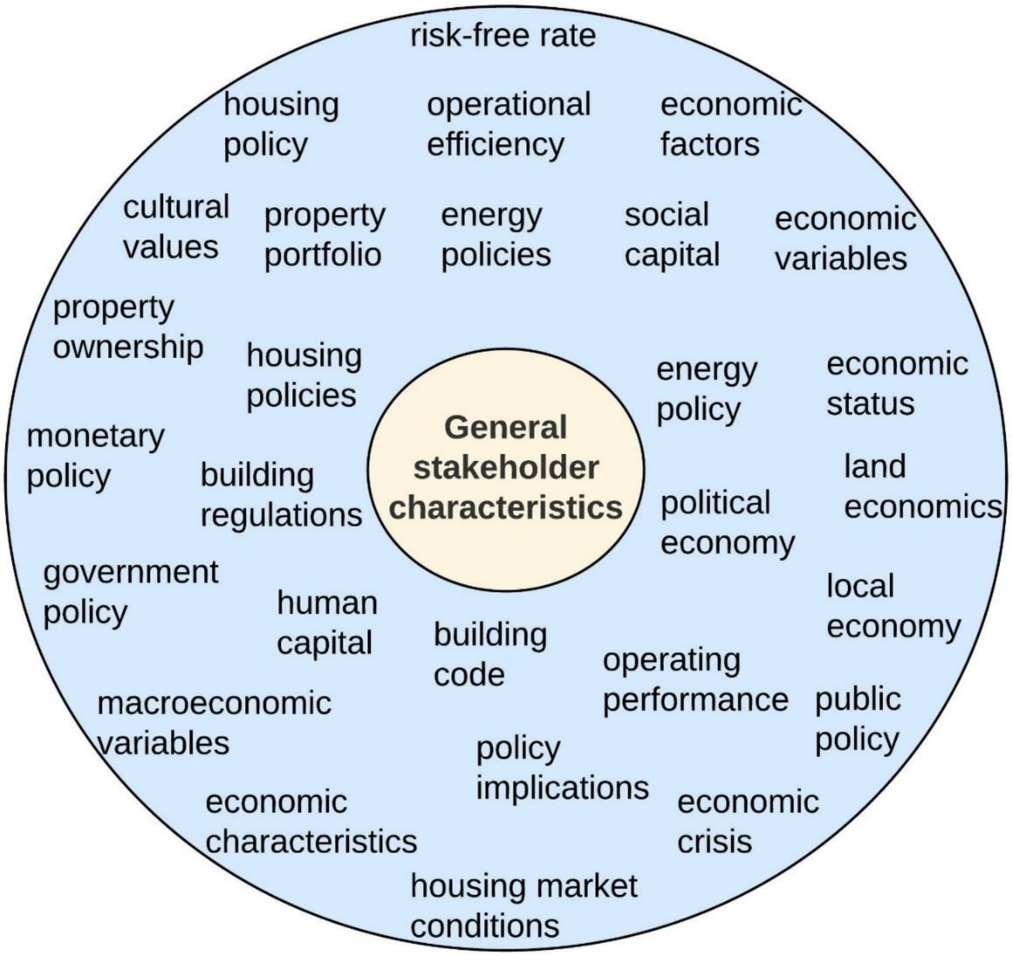


Figure 10: General stakeholder ecosystem characteristics

Situational characteristics were grouped into five categories to describe the context of building use: 1) the physical surroundings, 2) social surroundings, 3) temporal perspective, 4) task definition, 5) antecedent state. The physical surroundings may influence the building use situation for several reasons. First, the building itself creates an indoor/outdoor environment. The building may create an indoor environment, residential/housing/living environment, thermal and visual environment. The building acts as a spatio-temporal barrier evident in its conditions, physics, science, and environment. An occupant's perceived indoor environment may be influenced by their position in the building (e.g., the building floor or wing) or building technologies and interdependencies. As a system, the physical building is situated within an environment and is interdependent on those factors. The building itself may be in a shared setting with other structures for human activity, surrounded by different types of buildings, other properties, economic activity, as part of the building stock, neighboring community, gated communities, or built environment. The geographical area and population density (e.g., metropolitan/urban area, rural area) contextualize the physical building surroundings. Local climate-related variables such as climate conditions, zones, data, humid/dry, hot/cold, and wind make the physical building surroundings—the overall outdoor environment including the natural environment, and pollution also make up the environment. Social surroundings, environment, and spaces contextualized building use. Social exclusion, relations/interactions, support, integration, social groups, mix, cohesion, the sense of community, network, and other factors may influence building use for an individual/household or interest public entities. Social sustainability, responsibility, and network governance may affect organizations' building use.

The context of building use may be temporal. Factors like the future climate, marketing time, time on the market, marketing timing, the building life/age, or the build stage contextualize building use relative to the stakeholder. The building use situation may be contextualized by the features of a situation that include the pursuit of selecting, shopping for, or obtaining information about a general or specific purchase. In addition, a task may reflect different buyer and user roles and user roles anticipated by the individual (Belk, 1975) . Task dimensions define the nature and characteristics relative to the stakeholder role. Buyer task dimensions may include information about the purchase, such as risks associated with investing or owning the building and external implications or housing needs for public entities. Task dimensions may consist of social circumstances like the (psychosocial) work environment or social activities in the user role. Both roles may include economic dimensions (e.g., development, growth, impact) and environmental dimensions (e.g., environmental assessment, studies, sustainability, design and measures, control, management, ratings); project/property development/operation stage (e.g., building renovation, property redevelopment); and services (e.g., performance simulation and evaluation, management, processes, and controls). Environmental and biological states at the individual and group level may contextualize the antecedent state. Factors that may constitute the environmental state include environmental health, existing environmental problems, inequality, quality, satisfaction, and indoor air quality. Public entities set community health as an antecedent state. Factors that may constitute their biological state include thermal comfort, indoor operative temperature, current health status and risks, environmental health.

The building, an object, is multi-faceted as its performance is based on its impact as a product and property. As a product, it has dimensions and features and can be branded with different ratings/certifications with capabilities to control the environment it creates and manage resource inputs; also, it ages, has life stages, different functional requirements, and working conditions. As a system, it can be designed to minimize resource use, and it can exist in the context of other buildings with shared resources or features, common uses, or containing people of similar demographics. Product is property, with different types of ownership, characterized by the intended use of the space (i.e., type of work performed, living/accommodations), and urban planning typology. The use of this product produces carbon, a physical environment, requires maintenance, and has economic implications. It is used to deliver services for activities over time and may have different activities/operations. The performance of this product is at the system level, and resource efficiency can be measured; performance may be measured over different periods and measured for a single building.

The Multi-Stakeholder Longitudinal Building Value Model (MSLBVM)

An economic model to assess the building value for key stakeholders (i.e., its impact on stakeholders) was developed. Economic analyses were performed on two residential development situations - broken into four total scenarios– to evaluate the building value (i.e., the true impact of residential buildings). In situation A, a residential developer sells a developed single-family detached home to an owner-occupier in Chicago, IL. In situation B, the building value in a multi-family rental development scenario in Chicago, IL was assessed. The stakeholders with standing are those who directly pay for the residence's performance. Scenarios A1 and A2 were evaluated under the guise of the first situation; the developer and owner-occupier(s) pay for building performance. In scenarios B1 and B2, the developer and tenant were the stakeholders with standing. However, governments, businesses, and other individuals in the household may benefit from its performance and are included. These economic models accounted for tangible and intangible consequences for multiple external and internal stakeholders, using the methodology explained in Section 4.1 and logic presented in Figure 6. Recall, tangible and intangible consequences of building use were monetized as NPV using CBA or quantified using MAUT. On the former, the building NPV for stakeholders with standing were calculated from scenario-specific stakeholder costs and benefits subsequently described. The scenario-specific values for the building outcomes in Table 5 are detailed in Sections 9.9 and 9.10. On the latter, the monetary value for the "energy needs" consequence was unavailable positioning it as an accounting example for non-monetary building impacts.

Scenario A1 is the "no-action" alternative, for the present-day economics of the single-family home development and use; no-action meaning the existing, status quo economic process. In scenario A1, a developer sells a single-family home to an occupier in year 0. Then, the developer receives revenue totalling the home purchase price. The only homeownership benefit accounted for is the property appreciation captured in year 30, although explicit benefits such as utility rebates, a range of tax deductions, and the "forced savings" by incurring home equity exist. This scenario accounts solely for traditional economic factors. Correspondingly, the following assumptions safeguarded the analysis from an exaggeration of homeownership benefits: 1) the utility rebates are assumed nil, 2) taxpayers are assumed not to reap any homeownership tax benefits, 3) home equity is not accounted for as a benefit as well. The year 30 sale present value includes the tangible benefit of revenue, the intangible cost of stress, and the capital gains which were below taxable limits (i.e. the capital gained was $365K below the $500K limit as they purchased the house for $450K and sold it for $815K in year 30). In Scenario A2, the homeownership impacts in Scenario A1 are included in addition to the building outcomes, intangible effects, and externalities. Also, a cost premium for the developer is incurred and not transferred to the home purchaser in Scenario A2. This cost premium was included because green building development may incur 6.5% of additional costs (Kats & Alevantis, 2003), albeit this is the case for commercial buildings. Intangible impacts for the housing developer likely exist but were not identified in a literature review for Scenario A2.

Assumptions for all analyses:

- The household does not own a car
- Household annual energy consumption of 10,524 kWh/year (electricity only)
- Personal annual water consumption ranges from 100-300 gallons/day (EPA, 2021a)
- The average U.S. family of four monthly water cost is \$72.93 if each person uses 100 gallons/day (Tiseo, 2021). A conservative monthly water cost of triple the average U.S. family of four monthly water cost was inserted.
- 4.9 lbs per person per day of municipal solid waste generated (Environmental Protection Agency, 2021b)
- Household environmental footprint is 48 metric tons CO_2e/year (Jones & Kammen, 2011)

Scenarios A1 and A2 analysis assumptions:

- Household net income is \$150,000 with two taxpayers
- Year 0 - home construction and sale to four-person household
- Year 0 - household purchases a 2,400 ft^2 home for \$450,000 in Chicago, IL with a 20% downpayment toward a 30-year loan
- Year 30 - home sale, assuming the 2% appreciation rate in Chicago, IL (Divounguy & Hill, 2020)
- Seller pays the closing costs
- Closing costs are included in the purchase price at year 0 and year 30
- Scenario A2 - Year 0 - 6.5% total cost premium for the developer

Scenario B1 is the “no-action” alternative of the present-day economics of the multi-family rental development. In this scenario, a developer builds and leases apartments, and one unit is rented to a four-person household. The \$175 project cost per sq. ft for a mid-rise building was estimated from Hoyt & Schuetz (2020). The average number of units, square feet per unit, gross potential rent, rental revenue losses, other revenue gains, operating expenses, and capital expenditures were collected from the 2019 National Apartment Association Survey of Operating

Income & Expenses in Rental Apartment Communities by Munger & Smith (2019). Specifically, the mid and hi-rise operating income and expense data for individual meter and recovery system market rent properties were applied. Rental revenue losses may be due to rental concessions, model units, and vacancies. Parking and application fees are examples of other income sources. The developer's explicit benefits include property returns quantified as the net unlevered cash and net levered cash flow, and development returns such as the yield-on-cost. Investment property subsidies and tax deductions are expected, explicit benefits that may overestimate the benefits in this CBA; therefore, they were neglected. It was assumed the tenants leased the apartment after the building stabilized (i.e., the potential gross income could be generated at full capacity less vacancies) to focus the research scope. Consequently, the building impacts for their single unit were assessed, positioning this model to plug into existing multi-family financial analyses. Otherwise, building owner financial decisions such as construction loan conditions, permanent loan conditions, reversions, operating shortfalls, capitalized construction interest, or varying return metrics may emphasize owner goals. The developer's explicit costs and benefits of this multi-family development were quantified as net profit. In Scenario B1, the tenant paid explicit costs such as rent, utilities, and application fees and received explicit benefits such as building and in-unit amenities. The building amenities included a pet-friendly policy, fitness center, on-site management, and lobby (Koziarz, 2017). The in-unit amenities included hardwood floors, all appliances, and a balcony/patio (Koziarz, 2017).

Scenario B2 had the Scenario B1 impacts and the building outcomes, intangible impacts, and externalities. In Scenario B2, the intangible benefit of development efficiency compared to single-family home development (National Multifamily Housing Council, 2019) was captured. The total cost of developing one unit was estimated to be $127K compared to the development cost of $547K single-family detached home (National Multifamily Housing Council, 2019). The difference of $420K was the intangible benefit estimate assumed to occur as a one-time benefit represented in year 0 though it would happen during development. Renters are disproportionally affected by numerous intangible costs such as unpredictable housing expenditures, child development costs, and several health metrics. As an example, the monetary value of unexpected housing expenditures was considered. On the other hand, renters enjoy the intangible benefits of greater flexibility to downsize or move, lower commute times, psychological costs of buying and selling, and the stress of home maintenance. The monetary values of the latter three were considered in Scenario B2. The monetary value of lower commute time is estimated from the Department of Transportation (DOT) rule of thumb for local personal travel as 50% of the hourly median household income (United States Department of Transportation Office of the Secretary of Transportation, 2016). In 2019, the national median household income was $69,703(United States Department of Transportation Office of the Secretary of Transportation, 2016). Approximately 10.68 days were saved in 2020 from not commuting in Chicago (Esri, USGS | Texas Parks & Wildlife, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA. (n.d.). Under the assumption that commute time is 66% shorter living in Chicago instead of the suburbs, $2,794 may be saved annually living in a multi-family in Chicago. This estimate does not capture the additional benefits of walking or biking to work. The monetary value of unpredictable housing expenditure was estimated as the sum of the average cost of a local move in Chicago for a 2-bedroom and search costs. The average cost of a local move in Chicago for a 2-bedroom was $1,250 (Move, Inc., 2018). Search costs were estimated from the average 10.4 weeks spent searching the rental market (Zillow Group Inc., 2016) and the value of time as estimated from the DOT guidelines. Due to the household experience and type, the building outcomes minutely changed in Scenario B2 and A2 from Scenario A2.

Scenarios B1 and B2 owner assumptions:

- One-time intangible development benefit
- Only reoccurring externalities were evaluated

Scenarios B1 and B2 household assumptions:

- Four-person household lease a 2-bed, 1-bath, 891 sq. ft space for $1,465 monthly in year 0
- Household net income of $60,000
- Purchased a pet in year 1
- Experienced mild food insecurity in years 2 and 3 and recovered in year 4
- Experienced housing unaffordability in year 4

Financial analysis assumptions

- Discount rate for NPV analyses
- A nominal discount rate of 2.34%,

- A real discount rate of 12%,
- An inflation rate of 1.7%,
- A risk-free discount rate of 0.64%, and the
- April 2021 nominal interest rate 0.02% for D-NPV analyses

The cost-benefit analysis of scenarios A1 and A2 are presented in Tables 6, 7, and 8. Scenario A1 and A2 cash flows are displayed in Tables 6 and 7. The breakdown of owner-occupier costs and benefits in Scenario A1 are displayed in Figure 11. The breakdown of owner-occupier costs and benefits in Scenario A2 at the time of purchase, occupancy, and sale are displayed in Figures 12, 13, and 14 respectively. The cumulative net present value over 31 years in Table 8. The costs and benefits of the building outcomes qualitative study results are indicated with the item. The decoupled cashflow of Scenario A2 is displayed in the Table 9.

In Scenario A1, the building value for the owner-occupier begins at a loss due to the downpayment and debt incurred to purchase the house, as shown in Figures 11 and 15. This loss remained until the conventional primary benefit from owning the home is received in year 30, when the house is sold. In this scenario, the developer is disconnected from the building value after the year 0 sale. The owners and other occupants experience tangible and intangible building impacts resulting from building outcomes. The present value of building outcomes from phase 1 of this mixed-methods study is illustrated in Figure 16. The negative present value in year 0 was due to the owner-occupier paying upfront for additional energy savings measures that society and themselves benefit from later. The present value of building outcomes became positive after the first year and remained positive until the house sale in year 30. The negative present value in year 30 was due to the psychological stress of selling the home; however, that becomes largely positive when combined with the revenue from the sale in Scenario A2. In Scenario A2, the housing developer's profit reduced 96% from $40,950 to $14,362. However, the owner-occupier net benefits over 30 years, independent of societal benefits, were $1.3M, and the present value of future cash flows was net positive in Scenario A2, as illustrated in Figure 17. Therefore, the potential for the industry to capture this identified value beneficial for owner-occupiers exists.

Similarly, Scenario A2 highlighted the benefits society and utility companies incur from improved residential building performance. The opportunity for new partnerships or revenue streams from external beneficiaries was highlighted by accounting for externalities. Over 30 years, society received a $1.1M of net benefit and utility companies received $180K from energy demand load reduction benefits. Also, the decoupled free cash flow in Table 9 was lower than Scenario A2 free cash flow for the owner-occupier. However, the building value greatly exceeded the value indicated by the NPV in Scenario A2 due to the effect of a risk-free rate. The effect of the risk-free rate showed the building value could be discounted at a lower rate of 2% instead of 5%, and the total value of $1.9M over 30 years yielded almost an additional $20K a year.

Scenario A2 supports the recommendation for residential developers, owner-occupiers, utility providers, and governments to monetize building outcomes and distribution of the building. In the event of a 6.5% cost premium, the net present value remained positive. Additional revenue can be captured over time from the owner-occupier, utility company, or the local and state governments. Monetizing building outcomes could allow for different financial strategies enabling the owner-occupier and developer to benefit from improved residential building performance under new business models.

Table 6: Scenario A1 Cashflow

Scenario A1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Owner-occupier										
Tangible benefits	0	0	0	0	0	0	0	0	0	0
Tangible costs	90,000	35,109	33,437	31,845	30,328	28,884	27,509	26,199	24,951	23,763
Net Benefits	**(90,000)**	**(35,109)**	**(33,437)**	**(31,845)**	**(30,328)**	**(28,884)**	**(27,509)**	**(26,199)**	**(24,951)**	**(23,763)**
Housing Developer										
Tangible benefits	450,000	0	0	0	0	0	0	0	0	0
Tangible costs	409,050	0	0	0	0	0	0	0	0	0
Net Benefits	**40,950**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Scenario A1	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Owner-occupier	0	0	0	0	0	0	0	0	0	0
Tangible benefits	22,631	21,554	20,527	19,550	18,619	17,732	16,888	16,084	15,318	14,588
Tangible costs	**(22,631)**	**(21,554)**	**(20,527)**	**(19,550)**	**(18,619)**	**(17,732)**	**(16,888)**	**(16,084)**	**(15,318)**	**(14,588)**
Net Benefits										
Housing Developer	0	0	0	0	0	0	0	0	0	0
Tangible benefits	0	0	0	0	0	0	0	0	0	0
Tangible costs	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Net Benefits	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Scenario A1	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Owner-occupier	0	0	0	0	0	0	0	0	0	0	188,599
Tangible benefits	13,894	13,232	12,602	12,002	11,430	10,886	10,368	9,874	9,404	8,956	0
Tangible costs	**(13,894)**	**(13,232)**	**(12,602)**	**(12,002)**	**(11,430)**	**(10,886)**	**(10,368)**	**(9,874)**	**(9,404)**	**(8,956)**	**188,599**
Net Benefits											
Housing Developer	0	0	0	0	0	0	0	0	0	0	0
Tangible benefits	0	0	0	0	0	0	0	0	0	0	0
Tangible costs	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Net Benefits	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

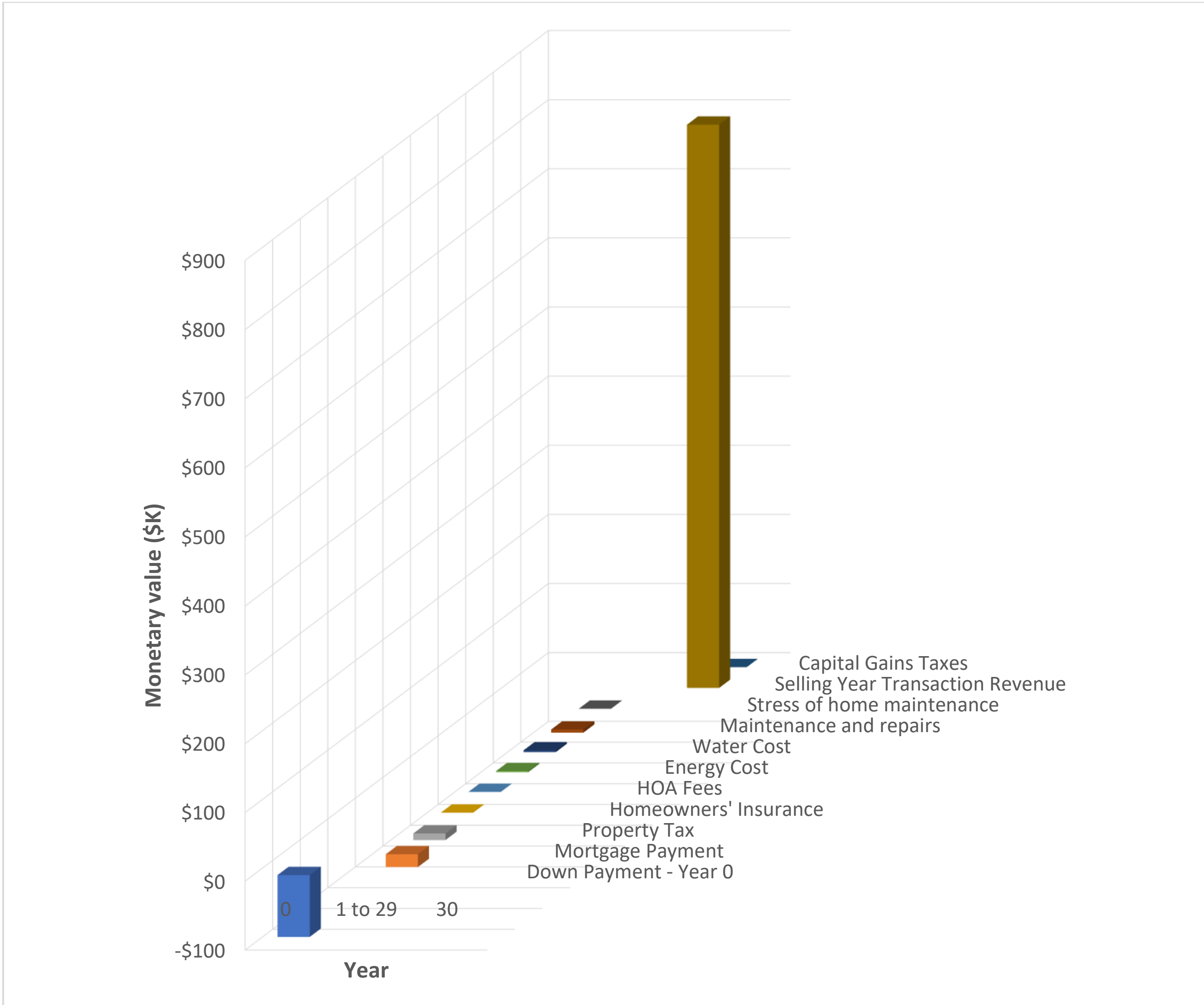


Figure 11: Scenario A1 Owner-occupier Impacts

Table 7: Scenario A2 Cashflow

Stakeholder	Year									
Owner-occupier	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Intangible benefits	0	0	0	0	0	0	0	0	0	0
Intangible costs	0	43	41	39	37	35	34	32	30	29
Building outcomes benefits		119,331	113,648	108,237	103,082	98,174	93,499	89,046	84,806	80,768
Building outcomes costs	63,277	3,869	3,685	3,510	3,343	3,183	3,032	2,887	2,750	2,619
Scenario A1 net benefits	(90,000)	(35,109)	(33,437)	(31,845)	(30,328)	(28,884)	(27,509)	(26,199)	(24,951)	(23,763)
Net Benefits	**(153,277)**	**80,310**	**76,486**	**72,843**	**69,375**	**66,071**	**62,925**	**59,928**	**57,075**	**54,357**
Housing Developer										
Intangible benefits	0	0	0	0	0	0	0	0	0	0
Intangible costs	0	45	43	41	39	37	35	34	32	30
Building outcomes benefits	450,000	0	0	0	0	0	0	0	0	0
Building outcomes costs	435,638	0	0	0	0	0	0	0	0	0
Net Benefits	**885,638**	**45**	**43**	**41**	**39**	**37**	**35**	**34**	**32**	**30**
Society										
Building outcomes benefits	1,150	595	566	539	514	489	466	444	423	402
Building outcomes costs	51,868	49,398	47,046	44,806	42,672	40,640	38,705	36,862	35,107	33,435
Net Benefits	**(50,718)**	**(48,804)**	**(46,480)**	**(44,267)**	**(42,159)**	**(40,151)**	**(38,239)**	**(36,418)**	**(34,684)**	**(33,032)**
Utility company										
Net Benefits	**10,965**	**10,443**	**9,945**	**9,472**	**9,021**	**8,591**	**8,182**	**7,792**	**7,421**	**7,068**

Table 7 continued

Stakeholder	**Year**									
Owner-occupier	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Intangible benefits	0	0	0	0	0	0	0	0	0	0
Intangible costs	28	26	25	24	23	22	21	20	19	18
Building outcomes benefits	76,922	73,259	69,770	66,448	63,284	60,270	57,400	54,667	52,064	49,584
Building outcomes costs	2,494	2,376	2,262	2,155	2,052	1,954	1,861	1,773	1,688	1,608
Scenario A1 net benefits	(22,631)	(21,554)	(20,527)	(19,550)	(18,619)	(17,732)	(16,888)	(16,084)	(15,318)	(14,588)
Net Benefits	**51,768**	**49,303**	**46,955**	**44,720**	**42,590**	**40,562**	**38,630**	**36,791**	**35,039**	**33,370**
Housing Developer										
Intangible benefits	0	0	0	0	0	0	0	0	0	0
Intangible costs	29	28	26	25	24	23	22	21	20	19
Building outcomes benefits	0	0	0	0	0	0	0	0	0	0
Building outcomes costs	0	0	0	0	0	0	0	0	0	0
Net Benefits	**29**	**28**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**
Society										
Building outcomes benefits	383	365	348	331	315	300	286	272	259	247
Building outcomes costs	31,843	30,326	28,882	27,507	26,197	24,950	23,761	22,630	21,552	20,526
Net Benefits	**(31,459)**	**(29,961)**	**(28,535)**	**(27,176)**	**(25,882)**	**(24,649)**	**(23,476)**	**(22,358)**	**(21,293)**	**(20,279)**
Utility company										
Net Benefits	**6,731**	**6,411**	**6,106**	**5,815**	**5,538**	**5,274**	**5,023**	**4,784**	**4,556**	**4,339**

Table 7 continued

Stakeholder	Year										
Owner-occupier	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Intangible benefits	0	0	0	0	0	0	0	0	0	0	0
Intangible costs	17	16	15	15	14	13	13	12	11	11	138
Building outcomes benefits	47,223	44,975	42,833	40,793	38,851	37,001	35,239	33,561	31,963	30,441	0
Building outcomes costs	1,531	1,458	1,389	1,323	1,260	1,200	1,143	1,088	1,036	987	0
Scenario A1 net benefits	(13,894)	(13,232)	(12,602)	(12,002)	(11,430)	(10,886)	(10,368)	(9,874)	(9,404)	(8,956)	188,599
Net Benefits	**31,781**	**30,268**	**28,827**	**27,454**	**26,147**	**24,901**	**23,716**	**22,586**	**21,511**	**20,487**	**188,460**
Housing Developer											
Intangible benefits	0	0	0	0	0	0	0	0	0	0	0
Intangible costs	18	17	16	15	15	14	13	13	12	11	11
Building outcomes benefits	0	0	0	0	0	0	0	0	0	0	0
Building outcomes costs	0	0	0	0	0	0	0	0	0	0	0
Net Benefits	**18**	**17**	**16**	**15**	**15**	**14**	**13**	**13**	**12**	**11**	**11**
Society											
Building outcomes benefits	235	224	213	203	194	184	176	167	159	152	144
Building outcomes costs	19,549	18,618	17,731	16,887	16,083	15,317	14,587	13,893	13,231	12,601	12,001
Net Benefits	**(19,313)**	**(18,394)**	**(17,518)**	**(16,684)**	**(15,889)**	**(15,133)**	**(14,412)**	**(13,726)**	**(13,072)**	**(12,450)**	**(11,857)**
Utility company											
Net Benefits	**4,132**	**3,936**	**3,748**	**3,570**	**3,400**	**3,238**	**3,084**	**2,937**	**2,797**	**2,664**	**2,537**

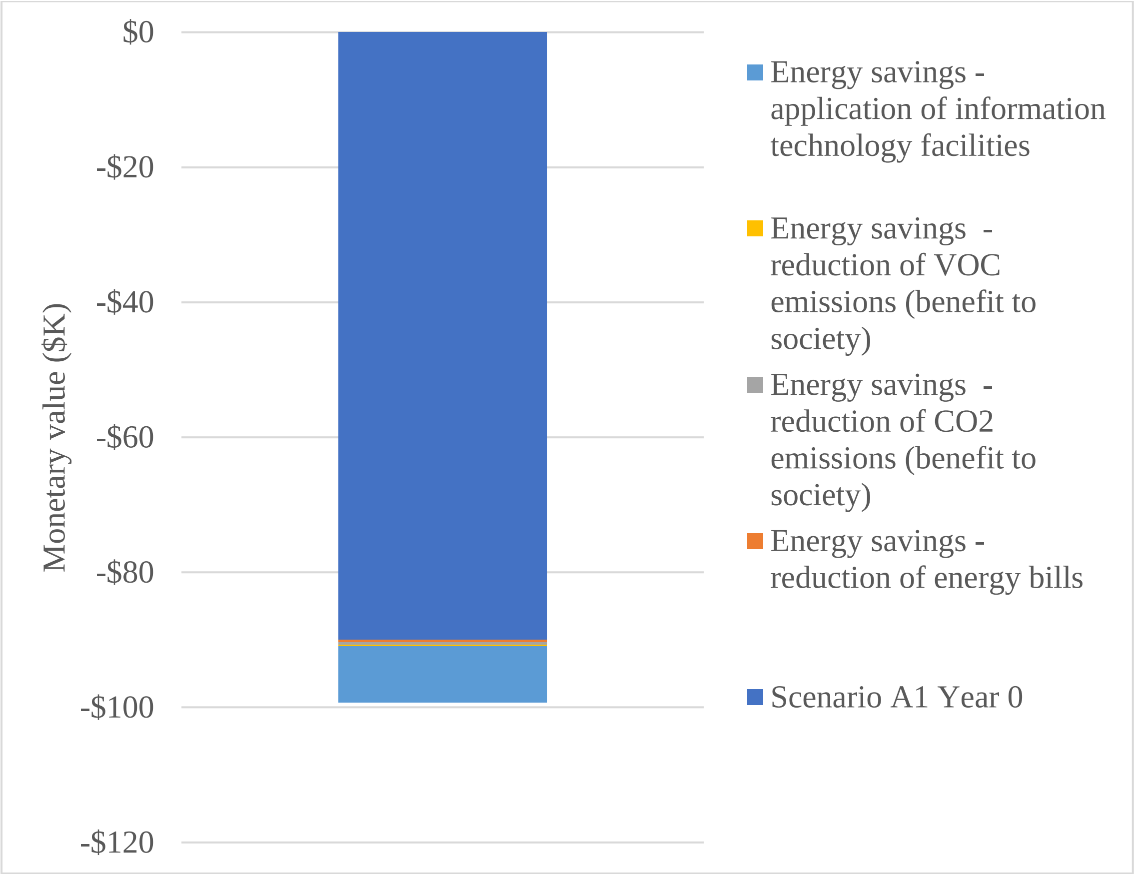


Figure 12: Scenario A2 Year 0 Owner-occupier Impacts

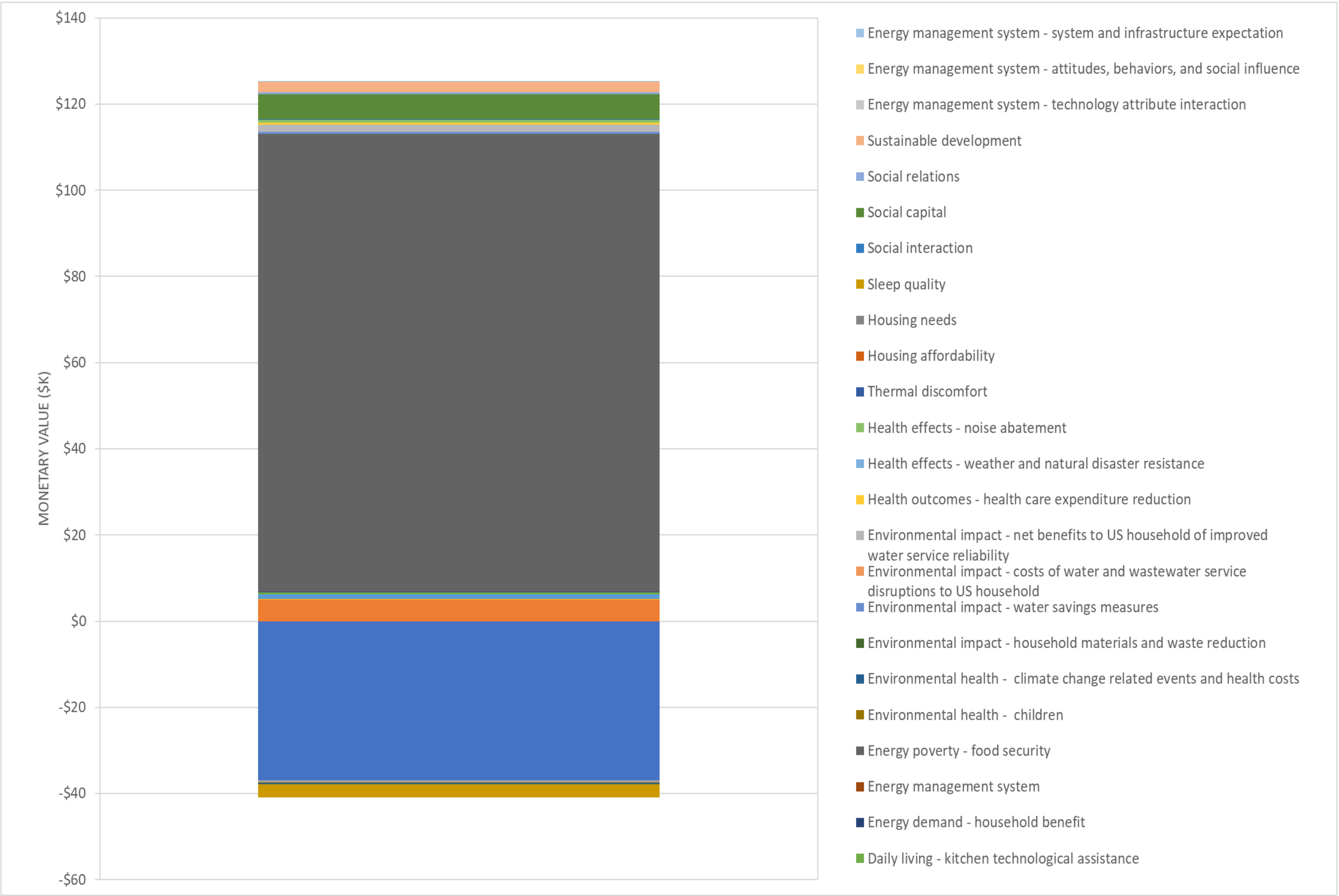


Figure 13: Scenario A2 Year 1-29 Owner-occupier Impacts

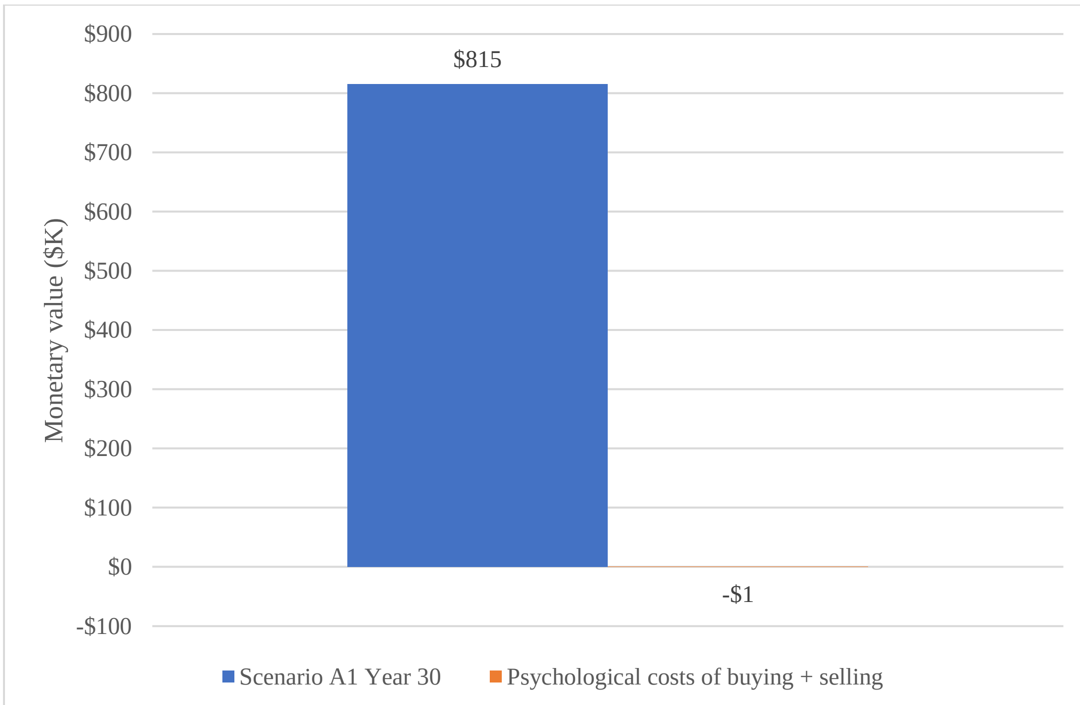


Figure 14: Scenario A2 Year 30 Owner-occupier Impacts

Table 8: Scenario A Cumulative NPV with externalities (italicized)

Explicit costs – development	**Scenario A1 ($)**	**Scenario A2 ($)**	**References**
Land acquisition cost			
Purchase Price	(83,250)		
Renovation			
Closing Costs			
Due Diligence			
Development costs			
Total Construction Costs	(274,950)		
Overhead/other Costs	(22,050)		
Finance Costs	(7,650)		
Marketing Costs	(4,500)		
Sales Costs	(16,650)		
Carry Costs			
Explicit costs – homeownership			
Down Payment – Year 0	(90,000)		
Financing Costs			
Mortgage Payment	(303,439)		
Mortgage Insurance			
Property Tax	(155,972)		
Homeowners’ Insurance			
HOA Fees	(1,637)		
Utility Costs			
Energy Cost	(25,846)		
Water Cost	(42,986)		
Maintenance and repairs	(73,676)		
Capital Gains Taxes			
Intangible costs – homeownership			
Psychological costs of buying + selling	(128)		
The stress of home maintenance	(737)		

Table 8 continued

Explicit benefits – development			
Home sale revenue	450,000		
Explicit benefits – homeownership			
Home Sale Revenue	188,599		
Building outcomes qualitative study results			
Comfort conditions		81,512	Buso et al. (2017)
Crime rate		(9,038)	Shapiro & Hasset (2012)
Daily living – improved mobility		3,561	Kabiri et al. (2018)
Daily living – personal care technological assistance		16,405	Schulz et al. (2013)
Daily living – kitchen technological assistance		7,702	
Energy demand – *(utility company benefit)*		179,519	Walton (2015)
Energy demand – household benefit		$2,585	Darby & McKenna (2012)
Energy management system		1,292	
Energy poverty – food security		1,737,183	Chavas (2017)
Energy poverty – frequent relocation / housing instability (costs to society)		(1,478)	Poblacion et al. 2017
Energy savings – reduction of energy bills		620	Park et al. (2013)
Energy savings - reduction of CO2 emissions (benefit to society)		(753)	
Energy savings - reduction of VOC emissions (benefit to society)		(559)	
Energy savings – application of information technology facilities		(8,326)	
Energy savings – measures		(308,274)	Banfi et al. (2008)
Environmental health – public costs (cost to society)		(559,059)	Anderko (2006)
Environmental health - children		(266)	Landrigan et al. (2002)
Environmental health - climate change-related events and health costs		(5,250)	Knowlton et al. (2011)
Environmental impact – household materials and waste reduction		293	

Table 8 continued

Environmental impact – water savings measures		1,474	Environmental Protection Agency (2021)
Environmental impact – costs of water and wastewater service disruptions to U.S. household		(301)	American Society of Civil Engineers (2020)
Environmental impact – net benefits to U.S. household of improved water service reliability		26,580	
Environmental impact – greenhouse gas emissions – climate change mitigations (benefit to society)		7,859	Dietz et al. (2009)
Health outcomes – health care expenditure reduction		9,431	Brennan et al. (2014)
Health effects – indoor air quality (benefit to society)		1,162	Anderko (2006)
Health effects – weather and natural disaster resistance		246	The National Institute of Building Sciences (2020)
Health effects – disaster-related response plans – FEMA mitigation grants total (benefit to society)		49	Rose (2007)
Health effects – noise abatement		9,194	Jiao et al. (2017) Swinburn et al. (2015)
Thermal discomfort		(1,417)	Bay et al. (2020)
Housing affordability		0	
Housing needs		110	Diamond & Mcquade (2019)
Sleep quality		(50,249)	Hafner et al. (2017)
Social interaction		(2,332)	Colombo & Luca (2014)
Social capital		94,262	Orlowski & Wicker (2015)
Social relations		9,070	Colombo & Luca (2014)
Sustainable development		40,241	Kats & Alevantis, (2003)

Table 8 continued

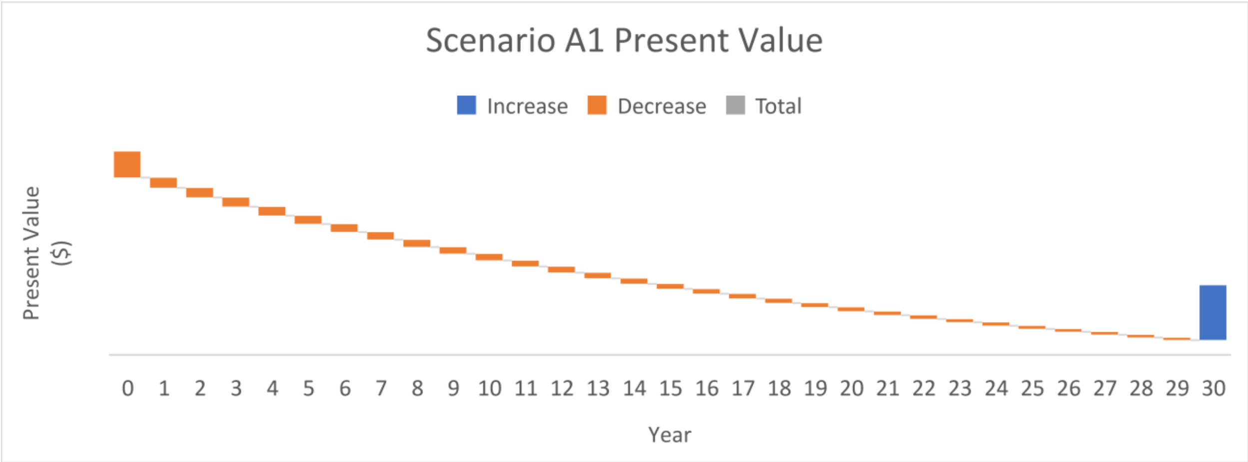
Energy management system – technology attribute interaction		208	Chen et al. (2020)
Energy management system – attitudes, behaviors, and social influence		411	
Energy management system – system and infrastructure expectation		212	
Housing needs – *benefits to society*		364	Diamond & Mcquade (2019)
Environmental health - environmental justice communities – infant mortality (cost to society)		(1,339)	Anderko (2006)
Housing affordability - cost to society		(287,337)	National Low Income Housing Coalition (n.d.)
Scenario Externalities			
Impact in a typical state - first-year benefits		347,619	National Association of Home Buildings (2015a)
Impact in a typical state - recurring impacts		894,044	
Impact on Local Area - first-year benefits		307,619	National Association of Home Buildings (2015b)
Impact on Local Area - recurring impacts		735,424	
Impact of Home Building in a typical local area - first-year net benefits		12,680	National Association of Home Buildings (2015c)
Impact of Home Building in a typical local area - average year net benefits		34,876	

Table 8 continued

Impact of Home Building in a state and local govt - first-year benefits		65,714	National Association of Home Buildings (2015d)
Impact of Home Building in a state and local govt - first-year costs		(23,943)	
Impact of Home Building in a state and local govt - after first-year benefits		158,166	
Impact of Home Building in a state and local govt - after first-year costs		(128,510)	
Impact of Home Building in a typical local area, state and in a state and local gov't- after 15 years benefits		632,264	
Impact of Home Building in a Typical State and in a state and local gov't- after 15-year costs		(422,674)	
Housing developer - benefits	450,000	450,000	
Housing developer - costs	(409,050)	(435,638)	
Housing developer - Net Benefits	**40,950**	**14,362**	
Owner-occupier - benefits	188,599	2,085,735	
Owner-occupier - costs	(648,843)	(773,766)	
Owner-occupier - Net Benefits	**(460,245)**	**1,311,969**	
Society - benefits		2,543,915	
Society - costs		(1,424,339)	
Society - Net Benefits		**1,119,576**	
Utility Company - Net Benefits		**179,519**	

Table 9: Scenario A2 Decoupled Cashflow

Year	**Cost of revenue risk (2.28%)**	**Cost of expense risk (1.79%)**	Building benefits	Building costs	Owner-occupier cash flow	Owner Cash Flow
0	**0**	**$0**	$0	**$0**	**-$90,000**	**$450,000**
1	**0**	$1,495	$124,862	$83,540	$42,545	
2	**0**	$1,495	$124,862	$83,540	$42,545	
3	**0**	$1,495	$124,862	$83,540	$42,545	
4	**0**	$1,495	$124,862	$83,540	$42,545	
5	**0**	$1,495	$124,862	$83,540	$42,545	
6	**0**	$1,495	$124,862	$83,540	$42,545	
7	**0**	$1,495	$124,862	$83,540	$42,545	
8	**0**	$1,495	$124,862	$83,540	$42,545	
9	**0**	$1,495	$124,862	$83,540	$42,545	
10	**0**	$1,495	$124,862	$83,540	$42,545	
11	**0**	$1,495	$124,862	$83,540	$42,545	
12	**0**	$1,495	$124,862	$83,540	$42,545	
13	**0**	$1,495	$124,862	$83,540	$42,545	
14	**0**	$1,495	$124,862	$83,540	$42,545	
15	**0**	$1,495	$124,862	$83,540	$42,545	
16	**0**	$1,495	$124,862	$83,540	$42,545	
17	**0**	$1,495	$124,862	$83,540	$42,545	
18	**0**	$1,495	$124,862	$83,540	$42,545	
19	**0**	$1,495	$124,862	$83,540	$42,545	
20	**0**	$1,495	$124,862	$83,540	$42,545	
21	**0**	$1,495	$124,862	$83,540	$42,545	
22	**0**	$1,495	$124,862	$83,540	$42,545	
23	**0**	$1,495	$124,862	$83,540	$42,545	
24	**0**	$1,495	$124,862	$83,540	$42,545	
25	**0**	$1,495	$124,862	$83,540	$42,545	
26	**0**	$1,495	$124,862	$83,540	$42,545	
27	**0**	$1,495	$124,862	$83,540	$42,545	
28	**0**	$1,495	$124,862	$83,540	$42,545	
29	**0**	$1,495	$124,862	$83,540	$42,545	
30	$18,557	$9	$815,113	$520	$790,982	



Utility company										
Net Benefits	**10,965**	**10,443**	**9,945**	**9,472**	**9,021**	**8,591**	**8,182**	**7,792**	**7,421**	**7,068**
Scenario A1 Impacts	**Year**									
Owner-occupier	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tangible benefits	0	0	0	0	0	0	0	0	0	0
Tangible costs	90,000	35,109	33,437	31,845	30,328	28,884	27,509	26,199	24,951	23,763
Net Benefits	**(90,000)**	**(35,109)**	**(33,437)**	**(31,845)**	**(30,328)**	**(28,884)**	**(27,509)**	**(26,199)**	**(24,951)**	**(23,763)**
Housing Developer										
Tangible benefits	450,000	0	0	0	0	0	0	0	0	0
Tangible costs	409,050	0	0	0	0	0	0	0	0	0
Net Benefits	**40,950**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 15: Present value of the building under current financial models

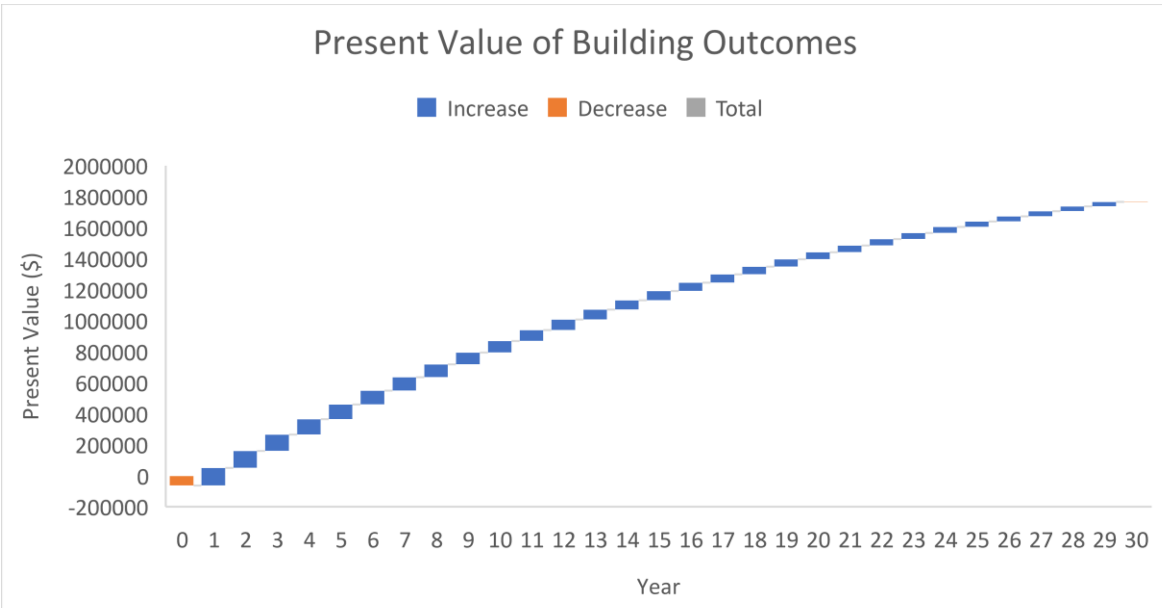


Figure 16: Present value of building outcomes included in Scenario A2

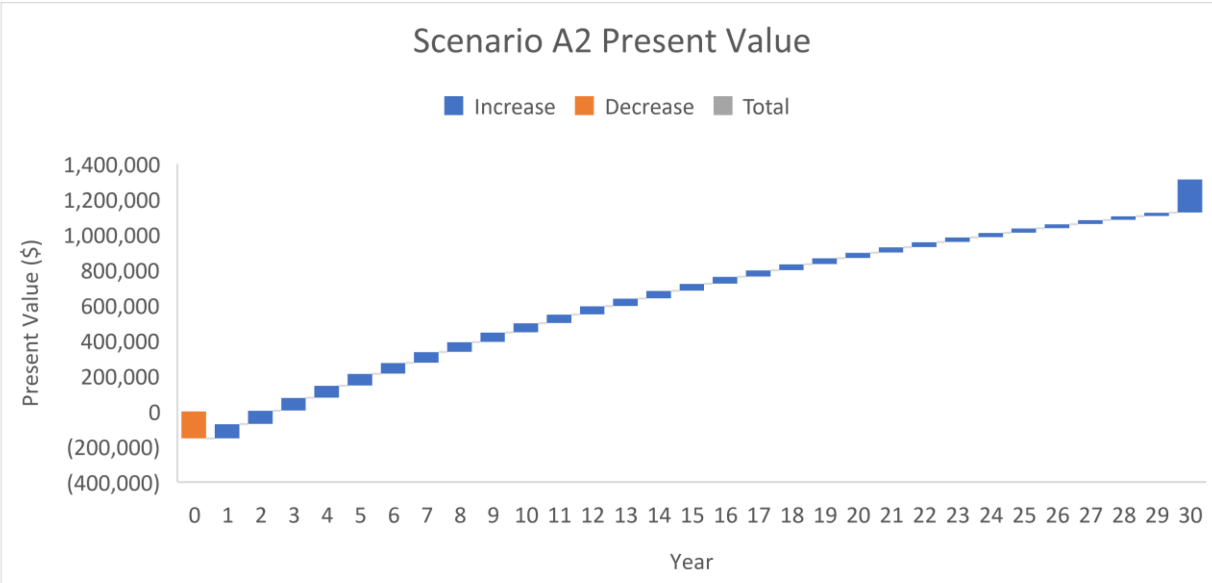


Figure 17: Present value of the building when capturing building outcomes

The CBA of a multi-family owner-tenant for the developer and owner is presented in Tables 10-13. The stakeholder cashflow in Scenarios B1 and B2 are in Tables 10 and 11 respectively. The costs and benefits of the building outcomes qualitative study results are indicated with the item. The building owner costs and benefits in Scenario B1 are shown in Figure 18. The intangible impacts and building outcomes for the owner are included in Figure 19. Similarly, the tenant impacts are highlighted in Figures 20 and 21 with the intangible impacts and building outcomes included in Figure 21. The cumulative NPV is shown in Table 12. The decoupled cashflow of Scenario B2 is presented in Table 13.

In Scenario B1, the building owner received net positive benefits year over year (refer to Figure 22) as the tenant building benefits remain stagnant (refer to Figure 25). Due to energy savings measures and the impact of crime on taxes, owner-related building outcomes are net negative, as shown in Figure 23. However, this net negative trend is offset by the significant net positive benefits from Scenario B1 in addition to the net intangible benefits. An investment in building outcomes may reduce the owner's net profit, as shown in Figure 24. However, the owner may have an opportunity to deliver and capture improved tenant outcomes, which are net positive in Figure 25. Delivering these outcomes may result in a positive net benefit for the tenant, as shown in Figure 25. In scenario B2, the NPV of the building for the owner and tenant was approximately

$464K and $242K, respectively. Scenario B2 NPV is 826% than the status quo scenario B1 for the owner due to the intangible benefit of development efficiency and 180% higher for the tenant. Given the reduction in net benefits for the owner in scenario B2, the D-NPV was computed to address potential risk. The decoupled NPV was calculated assuming the developer captured scenario B2 tenant impacts excluding utility costs paid to the utility company. Like scenario A2, the decoupled tenant cash flow presented in Table 9 was lower than scenario B2. However, the building value greatly exceeded the value indicated by the Scenario B2 NPV due to the effect of the risk-free rate. The effect of the risk-free rate showed that the building value could be discounted at a lower rate of 1% instead of 5% for the total value of $266K over five years; an additional $15K above scenario B2.

Over five years, society received approximately $152K net benefit, and utility companies gained $49K from energy demand load reduction benefits. Scenario B2 supports the recommendation for residential developers, owner-occupiers, utility providers, and governments to monetize building outcomes and distribution of the building. Additional revenue may be captured over time from the tenants, utility companies, or the local and state governments. Monetizing building outcomes could allow for different financial strategies enabling the tenant and developer to benefit from improved residential building performance under new business models.

The potential benefit of this methodology was the ability to quantitatively evaluate possible future practical events and consequences, and stakeholder implications. For example, in years 2 and 3, the tenants experience mild food insecurity, which lowered their net benefits by 78% from the previous year. The tenants experience housing unaffordability after recovering from mild food insecurity in year 4, reducing their net benefits by 15% from year 1. In reality, housing unaffordability and food insecurity have an aggregate impact on the tenant not reflected in this analysis; however, the potential benefit for the owner to have improved tenant outcomes was reflected.

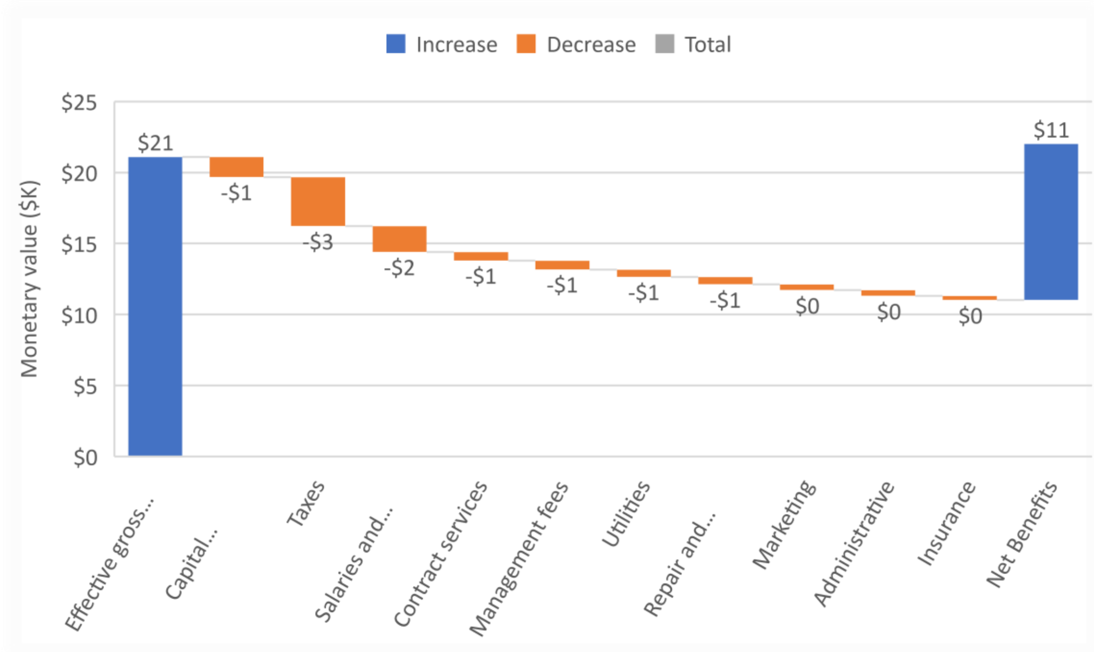


Figure 18: Scenario B1 Owner Net Benefits

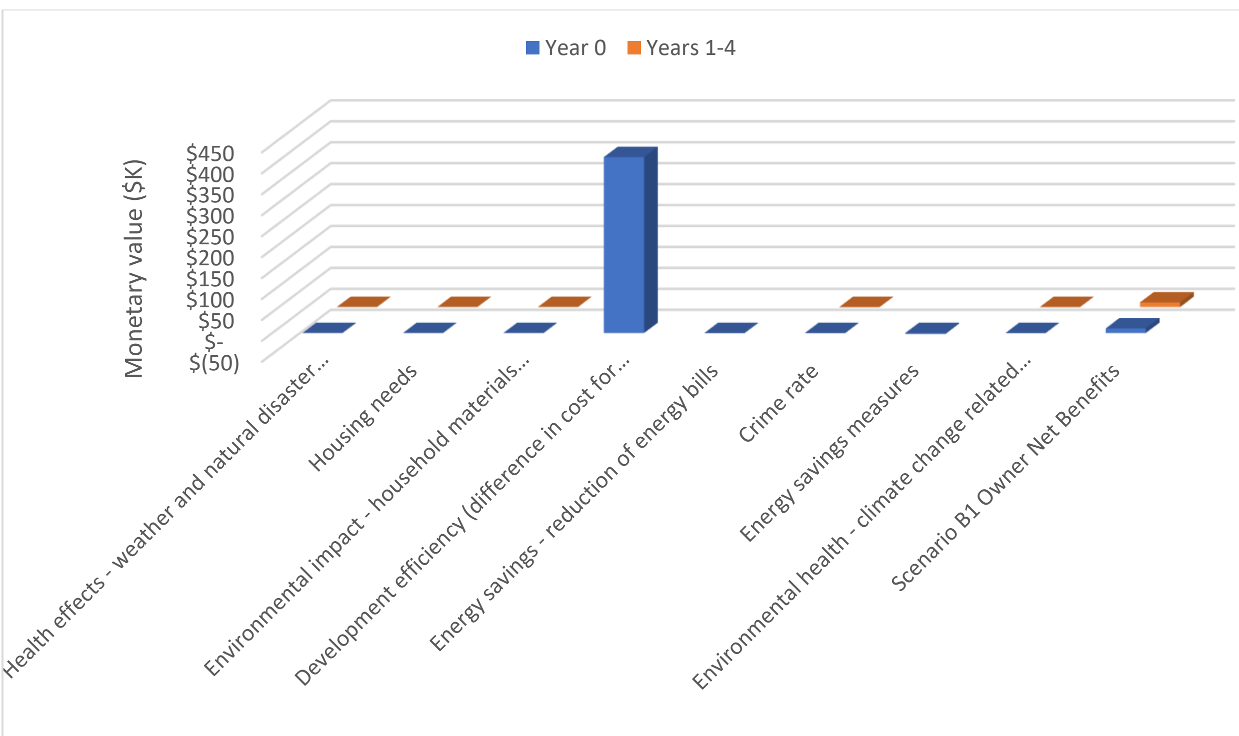


Figure 19: Scenario B2 Owner Net Benefits

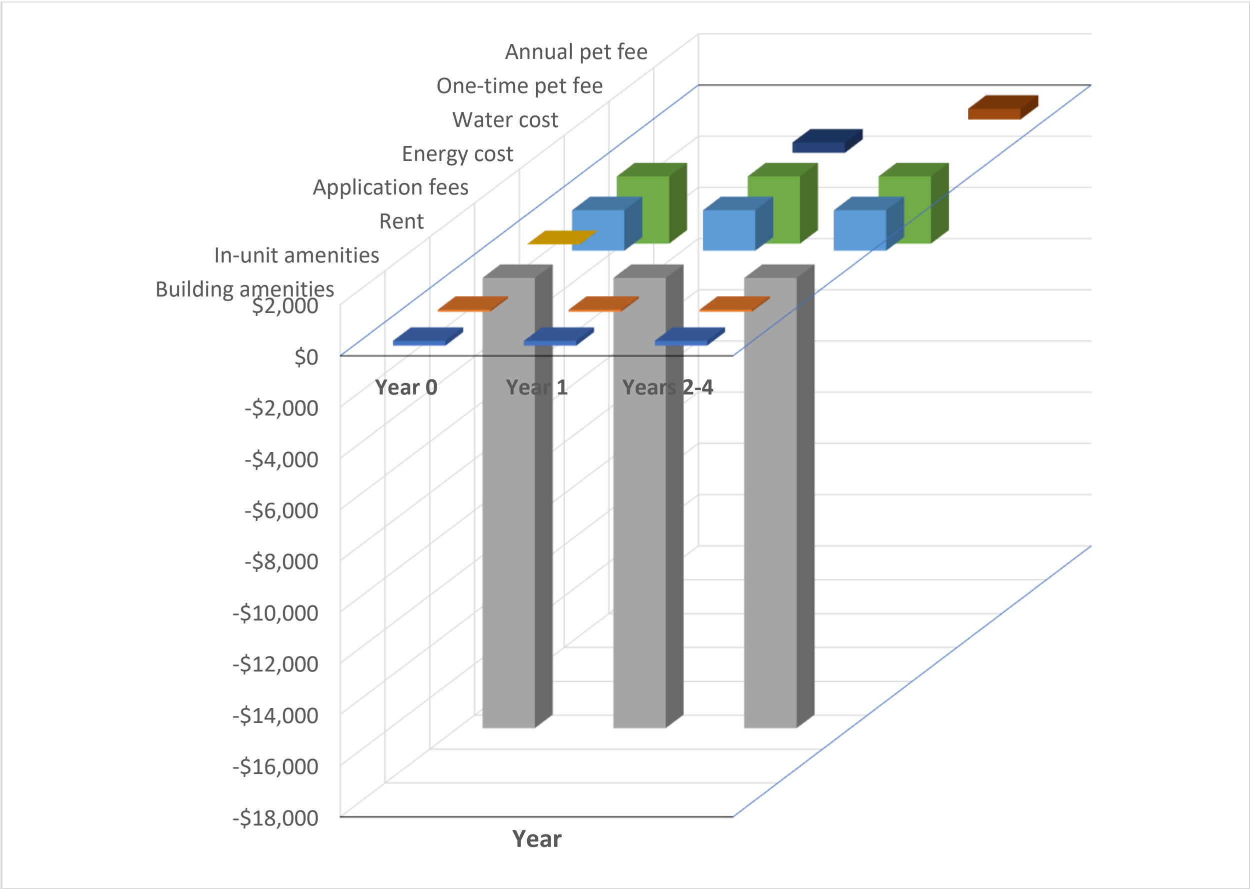


Figure 20: Scenario B1 Tenant Net Benefits

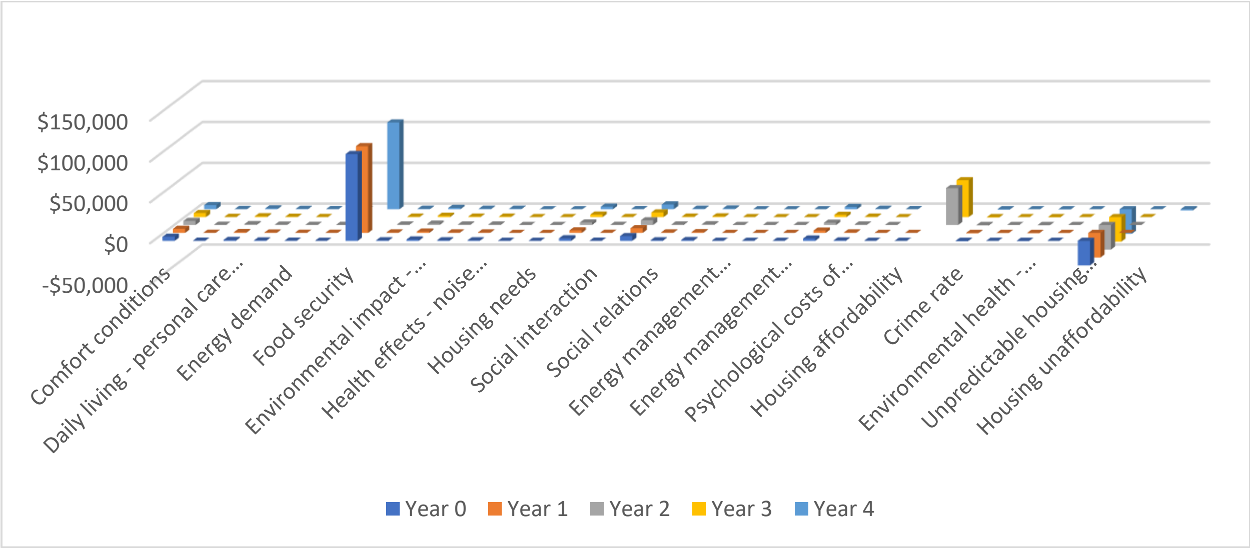


Figure 21: Scenario B2 Tenant Net Benefits

Table 10: Scenario B1 Annual Cashflow

Scenario B1			**Year**		
Tenant	**0**	**1**	**2**	**3**	**4**
Tangible benefits	265	265	265	265	265
Tangible costs	21,794	22,184	22,204	22,204	22,204
Net benefits	**(21,529)**	**(21,919)**	**(21,939)**	**(21,939)**	**(21,939)**
Housing Developer/Owner					
Tangible benefits	21,099	21,099	21,099	21,099	21,099
Tangible costs	10,086	10,086	10,086	10,086	10,086
Net benefits	**11,013**	**11,013**	**11,013**	**11,013**	**11,013**

Table 11: Scenario B2 Annual Cashflow

Scenario B2		**Year**			
Tenant	**0**	**1**	**2**	**3**	**4**
Intangible benefits	3,359	3,359	48,431	48,431	3,359
Intangible costs	30,105	30,105	30,105	30,105	31,556
Building outcomes benefits	126,824	126,840	20,736	20,736	126,840
Building outcomes costs	907	907	907	907	907
Scenario B1 net benefits	(21,529)	(21,919)	(21,939)	(21,939)	(21,939)
Net benefits	**77,641**	**77,267**	**16,215**	**16,215**	**75,796**
Housing Developer/Owner					
Intangible benefits	420,000	0	0	0	0
Intangible costs	0	0	0	0	0
Building outcomes benefits	41	41	41	41	41
Building outcomes costs	3,535	873	873	873	873
Scenario B1 net benefits	11,013	11,013	11,013	11,013	11,013
Net benefits	**427,518**	**10,181**	**10,181**	**10,181**	**10,181**
Society					
Building outcomes benefits	1,150	1,150	1,150	1,150	1,150
Building outcomes costs	51,868	51,868	51,868	51,868	51,868
Externalities	57,650	95,070	95,070	95,070	95,070
Net benefits	**6,932**	**44,352**	**44,352**	**44,352**	**44,352**
Utility Company Net Benefits	**10,965**	**10,965**	**10,965**	**10,965**	**10,965**

Table 12: Scenario B Cumulative NPV with externalities (italicized)

	Scenario B1 ($)	Scenario B2 ($)	References
EXPLICIT COSTS - Landlord			
Taxes	**(15,716)**		
Salaries and personnel	**(8,263)**		
Contract services	**(2,754)**		
Management fees	**(2,876)**		
Utilities	**(2,349)**		
Repair and maintenance	**(2,430)**		
Marketing	**(1,863)**		
Administrative	**(1,823)**		
Insurance	**(1,337)**		
Capital expenditures	**(6,440)**		
EXPLICIT BENEFITS - Landlord			
Gross potential revenue	**98,871**		
Other revenue	**5,995**		
Lost revenue	**8,951**		
Effective gross revenue	**95,914**		

Table 12 (continued)

INTANGIBLE BENEFIT - Development			
Development efficiency (difference in cost for a single unit)		**420,000**	(National Multifamily Housing Council, 2019)
EXPLICIT COST - Tenant			
Rent	**(79,918)**		
Application fees	**(10)**		
One-time pet fee	**(381)**		
Annual pet fee	**(1,089)**		
Energy cost	**(7,176)**		
Water cost	**(2,046)**		
INTANGIBLE COST - Tenant			
Unpredictable housing expenditures		**(136,857)**	
EXPLICIT BENEFIT - Tenant			
Building amenities	**850**		
In-unit amenities	**355**		
INTANGIBLE BENEFIT - Tenant			
Less than 30 mins commute		**12,701**	
Psychological costs of buying selling		**2,364**	
Stress of home maintenance		**205**	

Table 12 (continued)

BUILDING OUTCOMES QUALITATIVE STUDY RESULTS			
Comfort conditions (benefit to the tenant)		**22,632**	Buso et al. (2017)
Crime rate (cost to the owner if in state) (cost to tenant)		**(2,509)**	Shapiro & Hasset (2012)
Daily living - improved mobility (not specific to homes) (benefit to the tenant)		**989**	Kabiri et al. (2018)
Daily living - personal care technological assistance (benefit to the tenant)		**4,555**	Schulz et al. (2013)
Daily living - kitchen technological assistance (benefit to the tenant)		**2,138**	
Energy demand - (utility company benefit)		**49,845**	Walton (2015)
Energy demand - household benefit (benefit to the tenant)		**718**	Darby & McKenna (2012)
Energy management system (benefit to the tenant)		**359**	
Energy poverty - food security (benefit to the tenant)		**374,264**	Chavas (2017)
Energy poverty - frequent relocation / housing instability (costs to society)		**(410)**	Poblacion et al. 2017
Energy savings - reduction of energy bills (benefit to the tenant)		**433**	Park et al. (2013)
Energy savings - reduction of CO2 emissions (benefit to society)		**469**	
Energy savings - reduction of VOC emissions (benefit to society)		**275**	
Energy savings - application of information technology facilities		**8,326**	
Energy savings - measures (quantify benefits for thermal comfort, air quality, noise protection) (cost to the owner)		**(2,285)**	Banfi et al. (2008)
Environmental health - public costs (cost to society)		**(155,228)**	Anderko (2006)
Environmental health - children (cost to the tenant)		**(74)**	Landrigan et al. (2002)
Environmental health - climate change related events and health costs (cost to the tenant) (cost to the owner)		**(1,458)**	Knowlton et al. (2011)

Table 12 (continued)

Environmental impact - household materials and waste reduction (benefit to owner)		**81**	
Environmental impact - water savings measures (benefit to the tenant)		**409**	Environmental Protection Agency (2021)
Environmental impact - costs of water and wastewater service disruptions to US household (cost to the tenant)		**(84)**	American Society of Civil Engineers (2020)
Environmental impact - net benefits to US household of improved water service reliability (benefit to the tenant)		**7,380**	
Environmental impact - greenhouse gas emissions - climate change mitigations (benefit to society)		**2,182**	Dietz et al. (2009)
Health outcomes - health care expenditure reduction (benefit to the tenant)		**2,618**	Brennan et al. (2014)
Health effects - indoor air quality (benefit to society)		**323**	Anderko (2006)
Health effects - weather and natural disaster resistance (benefit to owner)		**68**	The National Institute of Building Sciences (2020)
Health effects - disaster-related response plans - FEMA mitigation grants total (benefit to society)		**14**	Rose (2007)
Health effects - noise abatement (benefit to the tenant)		**2,553**	Jiao et al. (2017)
Thermal discomfort (benefit to the tenant)		**157**	Swinburn et al. (2015) Bay et al. (2020)
Housing affordability (costs to the tenant)		**1,194**	
Housing needs - benefits to the tenant		**35**	Diamond & Mcquade (2019)
Sleep quality (benefits to the tenant)		**13,952**	Hafner et al. (2017)
Social interaction (benefits to the tenant)		**648**	Colombo & Luca (2014)

Table 12 (continued)

Social capital (benefits to the tenant)		**26,173**	Orlowski & Wicker (2015)
Social relations (benefits to the tenant)		**2,518**	Colombo & Luca (2014)
Sustainable development (benefit to the tenant)		**4,148**	Kats & Alevantis, (2003)
Energy management system - technology attribute interaction (benefit to the tenant)		**58**	Chen et al. (2020)
Energy management system - attitudes, behaviors, and social influence (benefit to the tenant)		**114**	
Energy management system - system and infrastructure expectation (benefit to the tenant)		**59**	
Housing needs - benefits to society		**101**	Diamond & Mcquade (2019)
Environmental health - environmental justice communities - infant mortality (cost to society)		**(372)**	Anderko (2006)
Housing affordability - cost to society		**(79,781)**	National Low Income Housing Coalition (n.d.)
Housing needs - benefits to the owner		**36**	
EXTERNALITIES			
Impact in a typical state - recurring impacts		**132,689**	National Association of Home Buildings (2015a)
Impact on Local Area - recurring impacts		**141,061**	National Association of Home Buildings (2015b)
Impact of Home Building in a typical local area - average year net benefits		**40,385**	National Association of Home Buildings (2015c)

Table 12 continued

Impact of Home Building in a state and local govt - after first-year net benefits		**70,789**	National Association of Home Buildings (2015d)
Owner - Net Benefits	**50,063**	**463,619**	
Tenant - Net Benefits	**(99,305)**	**242,300**	
Society - Net Benefits		**152,497**	
Utility Company – Net Benefits		**49,845**	

Table 13: Scenario B2 Decoupled Cashflow

Year	Building benefits	Building costs	Cost of revenue risk (5.28%)	Cost of expense risk (5.45%)	Decoupled cash flow
0	$130,390	$48,603	$6,878	$2,649	$77,065
1	$130,028	$48,974	$6,859	$2,669	$76,376
2	$68,996	$49,013	$3,640	$2,671	$18,895
3	$68,996	$49,013	$3,640	$2,671	$18,895
4	$130,028	$50,464	$6,859	$2,750	$74,976

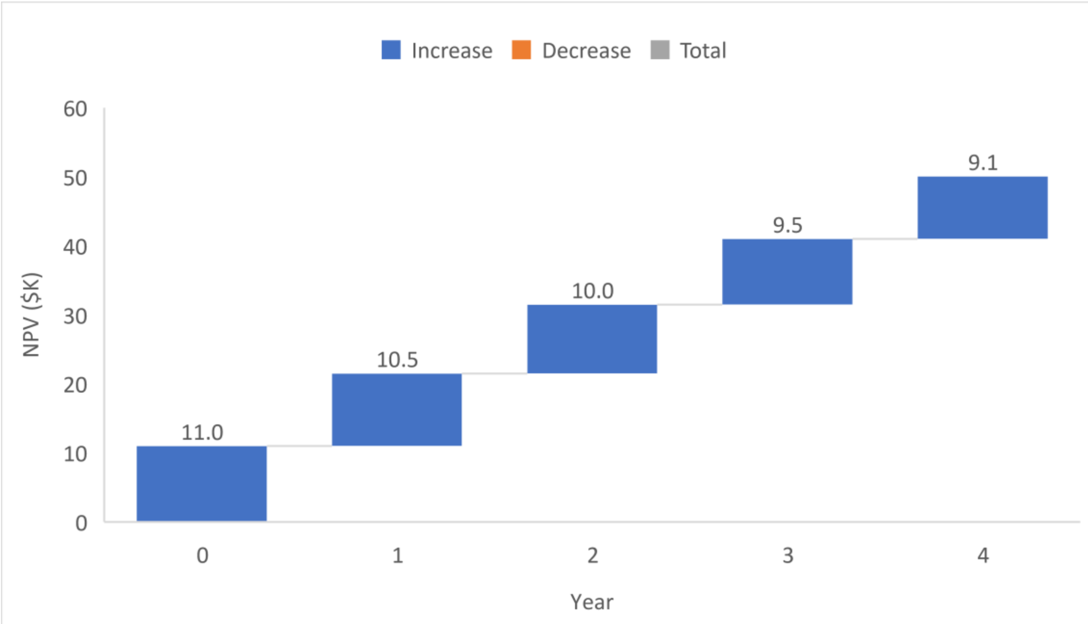


Figure 22: Scenario B1 present value of the building for the owner

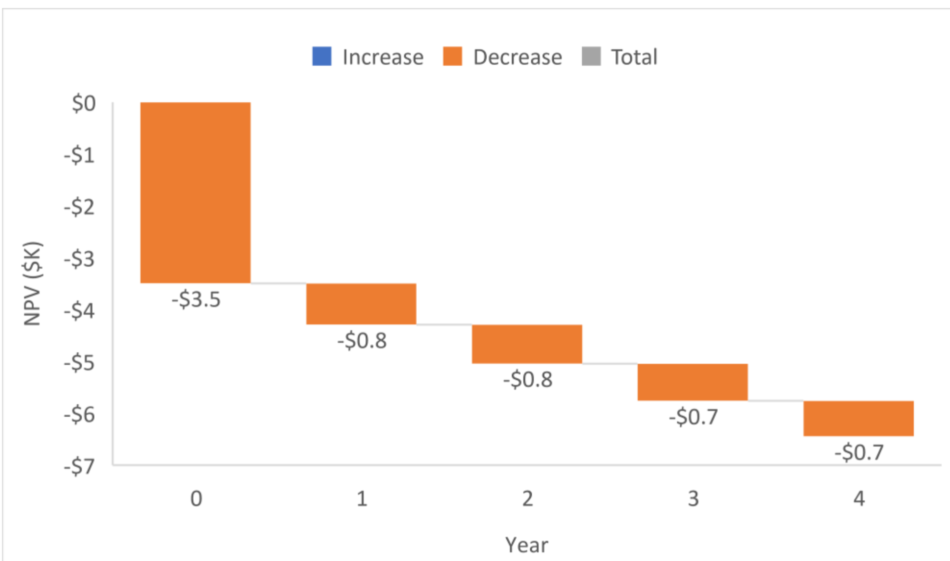


Figure 23: Present value of building outcomes for the owner included in Scenario B2

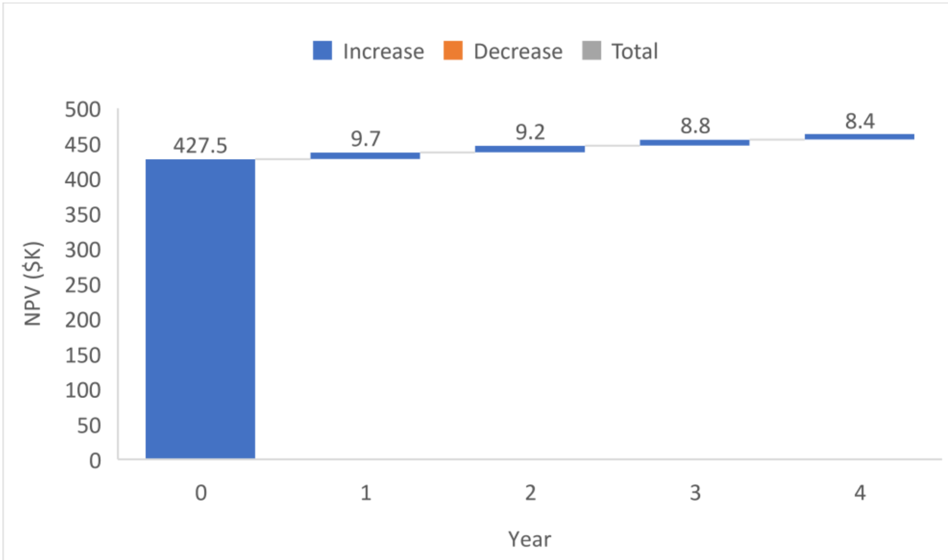


Figure 24: Present value of the building when capturing building outcomes in Scenario B2

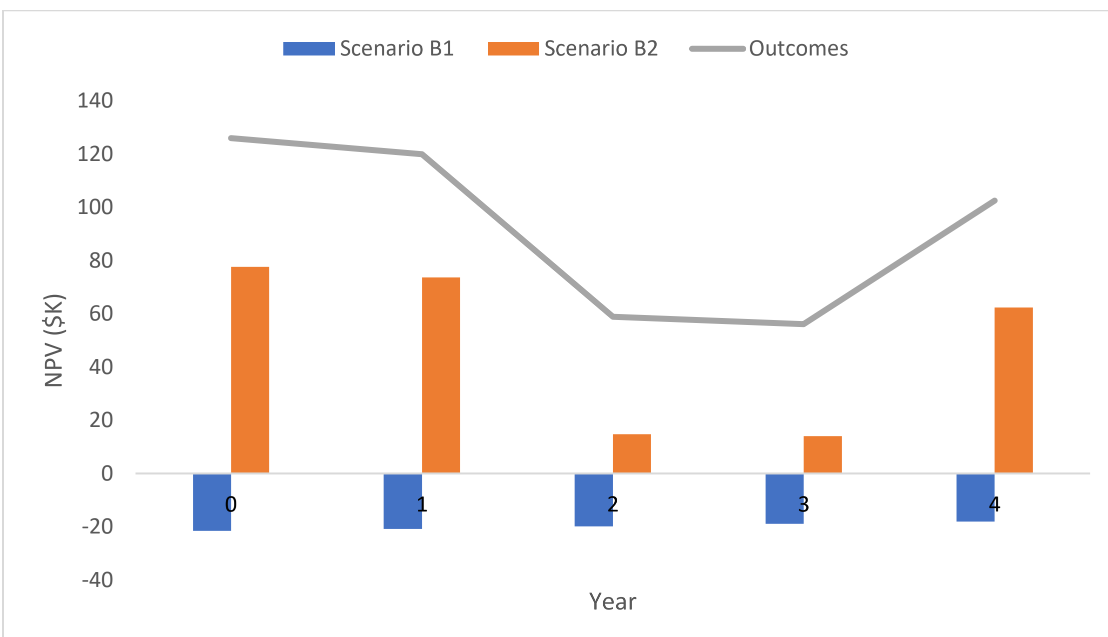


Figure 25: Present value of the building for the tenant

Sensitivity analyses

Sensitivity analyses on key assumptions in scenarios A2 and B2 were conducted to determine if the net present value sign changed at different discount rates ranging from 0-15%. In Scenario A2, the owner-occupier NPV sensitivity to the largest building impacts of property appreciation rate, food security, social capital, and comfort conditions, and energy savings measures were evaluated. Also, the influence of the downpayment and loan term was assessed because financing may be a barrier to high homeownership benefits. As shown in Figure 26, the NPV remained positive with minimal change with decreasing comfort condition benefits. However, the owner-occupier's NPV dropped almost 10% with a 5% discount rate increase. The NPV dropped 58%, 48%, and 40% from 0-5%, 5-10%, and 10-15% discount rates respectively under the same comfort condition benefit. Therefore, the monetary benefit of comfort conditions was sensitive to discount rate. The effect of social capital benefit illustrated a similar pattern (see Figure 27). The housing ventilation system was one of the highest value energy savings measures. Other measures such as professional energy audits and new windows ranged from $105 to $58,000. Across this range in Figure 28, the owner-occupier NPV remained positive and relatively stagnant with increasing savings measures costs. Also, the NPV reduced 56%, 46%, and 37% from 0-5% 5-10% and 10-15% discount rates, respectively; similar to the effect of changing discount rates on the benefit of comfort conditions and social capital. The owner-occupier NPV was highly sensitive to the net benefit of food security, and the food security benefit was sensitive to the discount rate as shown in Figure 29. Negative value was generated for food security benefits of $38K or lower at higher discount rates. For example, assuming the net benefits of mild food insecurity and food security for this 4-person household were approximately $45K and $106K, respectively, as Chavas (2017) estimated, the NPV dropped 57% from 0-5% discount rate, 47% from 5-10% discount rate and 39% from 10-15% discount rate benefit around the food security limit. The NPV dropped 71% from 0-5% discount rate, 70% from 5-10% discount rate and 86% from 10-15% discount rate with mild food insecurity.

As expected, the owner-occupier building value was not highly sensitive to the loan term, but significantly less value may be obtained at higher discount rates as shown in Figure 31. Also, as expected, the owner-occupier building value drastically reduced with higher downpayments and higher discount rates in Figure 32. Interestingly, the gradual reduction from 18-20% downpayment indicated a slower pace of increasing the building value at higher downpayments and high discount rates. In Figure 30, the owner-occupier NPV was highly sensitive to higher property appreciation rates, and the appreciation rate was susceptible to higher discount rates. At 2% appreciation, the owner-occupier NPV dropped 58%, 48%, and 40% with 5% discount rate step increases; these owner-occupier NPV differences grew at higher appreciation rates.

Scenario B2 tenant NPV sensitivity to food security, social capital, and rent were evaluated due to their significant value for the tenant. The family in scenario B2 experienced food security and mild food insecurity, approximately \$106K and \$45K annual benefits, respectively. If the family experienced high food insecurity, the annual net benefit would drop to roughly \$11.9K. Figure 33 illustrated the financially precarious situation as the net present value of the building was near \$0 in the latter case. The tenant NPV remained positive at a 15% discount rate with \$0 benefit of social capital reducing 22% to approximately \$196K; its stability is shown in Figure 34. The tenant NPV remained net positive with increasing discount rates as shown in Figure 35. However, a \$100 rent increase (roughly 7%) resulted in a 2% decrease in NPV at the same discount rate and a near 15% reduction at a 15% discount rate. A two-hundred dollar increase in rent resulted in more than 4% NPV reduction at the original discount rate and nearly 17% NPV reduction at 15% discount rate. The building value for the tenant may not be susceptible to rent increase above the accepted affordability measure of 30% of the household income (\$35 more). However, to pay rent, other household expenses may be reduced.

Scenario B2 owner NPV sensitivity to taxes, capital expenditures, and development efficiency were evaluated for their weighty importance to the building value. As shown in Figure 37, if taxes increased by \$1,000 (29%), the owner building value would decrease 1% at the 5% discount rate and above 2% at a 15% discount rate. Similarly, if the taxes increased by \$5,000 (144%), the owner building value would decrease almost 5% at the 5% discount rate and nearly 6% at the 15% discount rate. Therefore, the owner building value is not sensitive to a change in taxes per apartment unit basis. The cumulative effects for 333 units may be significant but may also be deducted when taxes are filed. An additional ten thousand dollars of capital expenditures (706% increase) resulted in a 9.81% decrease in building value at the same discount rate and a 9.8% decrease at a 15% discount rate. The capital expenditure effect on the building value was less dependent on the discount rate as shown in Figure 38. Contrary to all other sensitivity analyses, the net present value increased at higher discount rates at a \$20K increase in capital expenditures. The owner building value remained net positive with \$0 of development efficiency as shown in

Figure 36. However, a $25K increase in development efficiency increased the owner's building value by 57%. An additional $25K step increase in development efficiency to $50K, $75K, and $100K improved the NPV 36%, 27%, and 21% respectively.

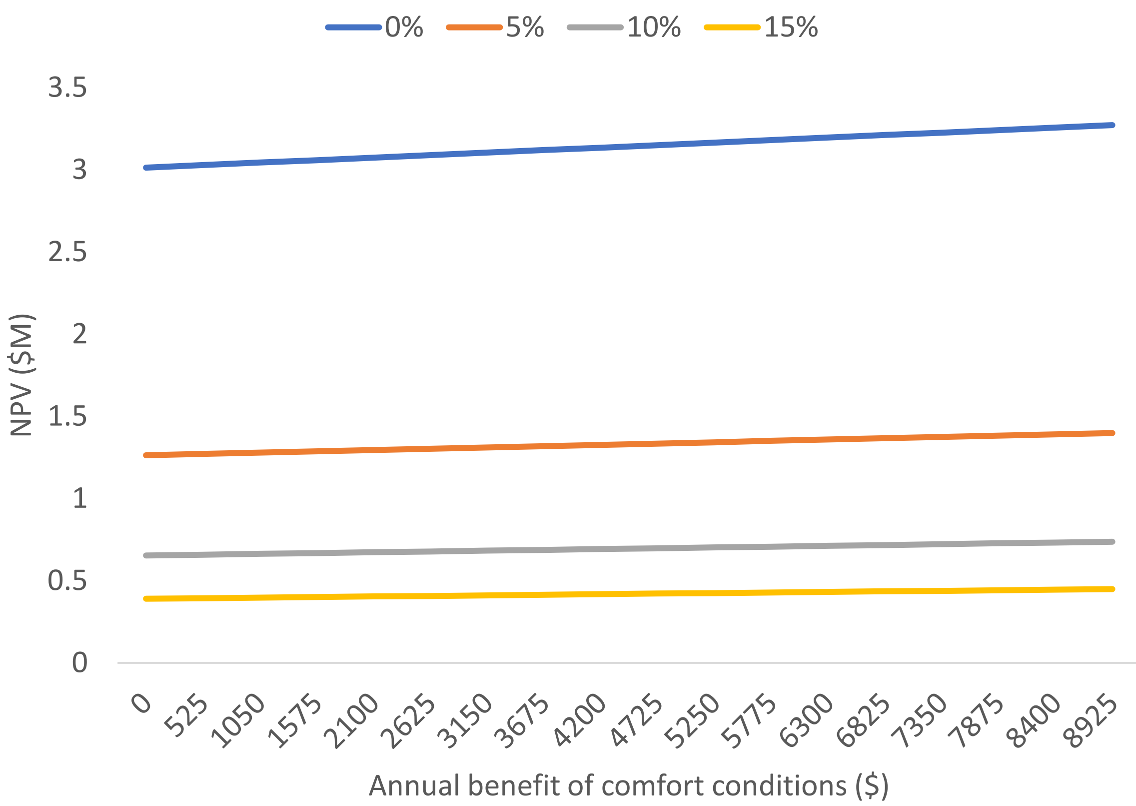


Figure 26: Scenario A2 Comfort Conditions

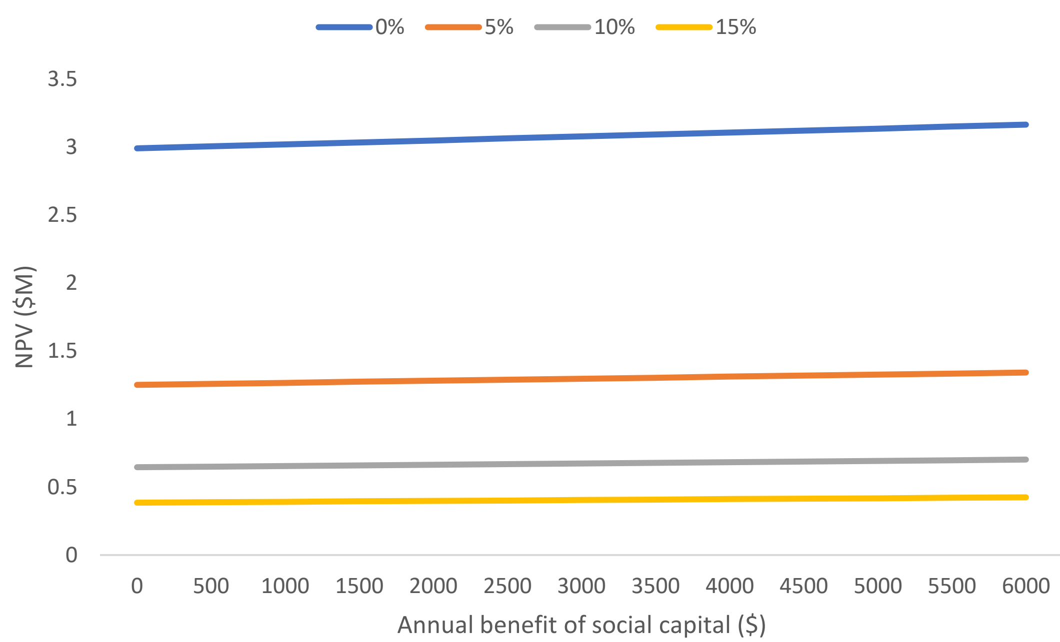


Figure 27: Scenario A2 Social Capital

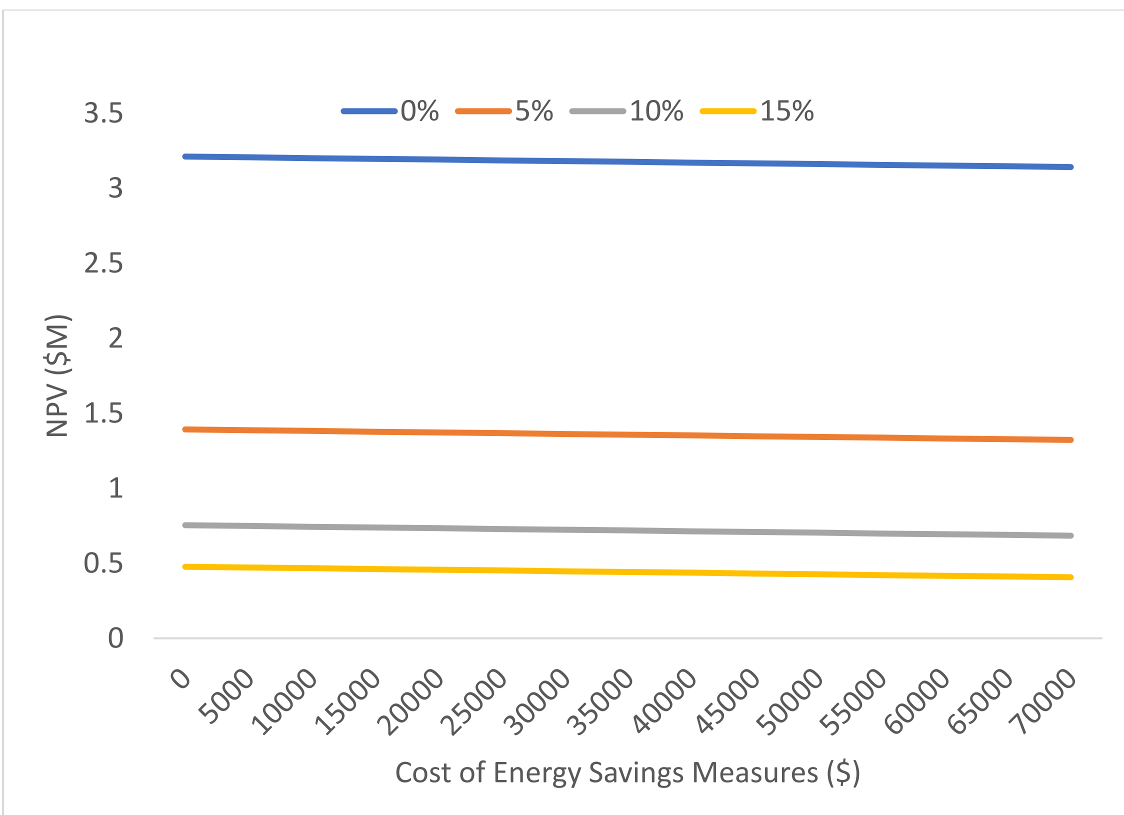


Figure 28: Scenario A2 Energy Savings Measures

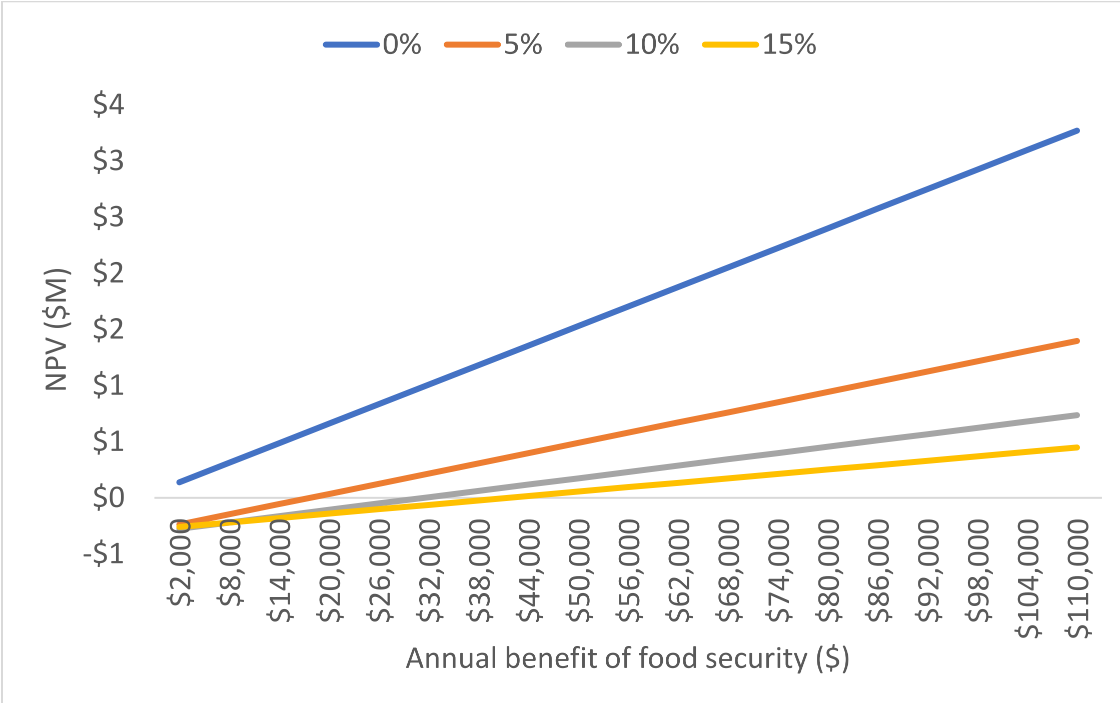


Figure 29: Scenario A2 Owner-Occupier Food Security

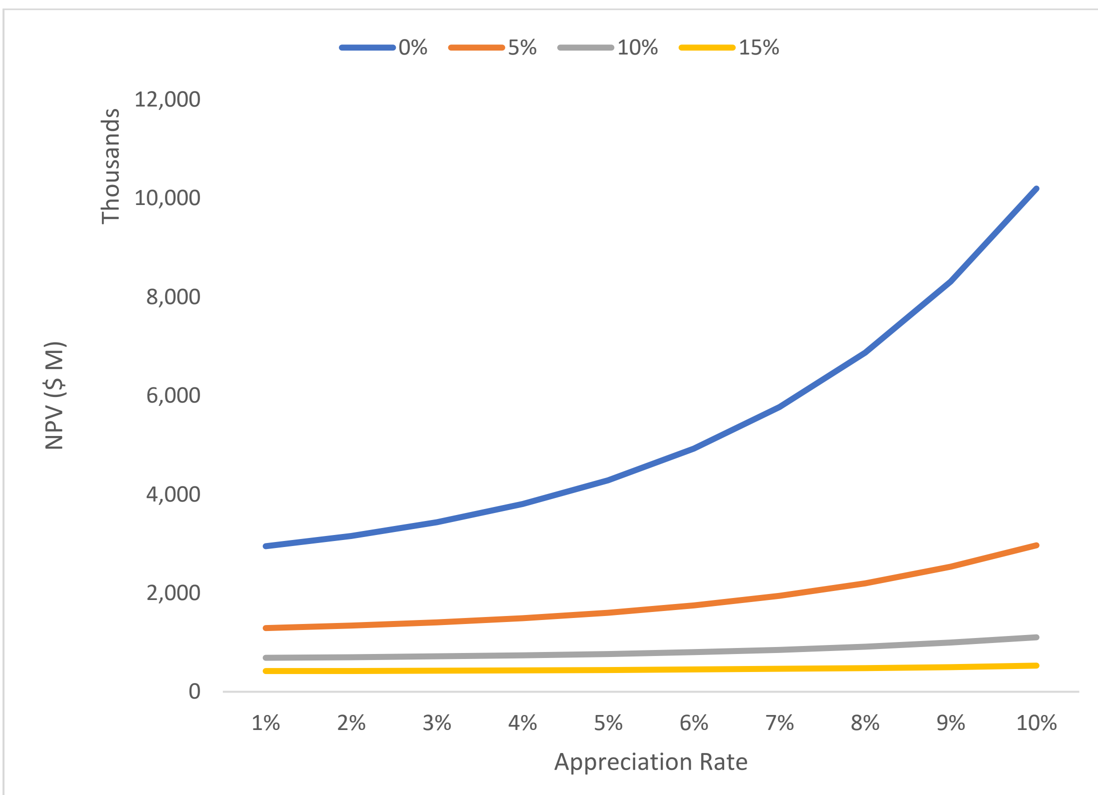


Figure 30: Scenario A2 Property Appreciation

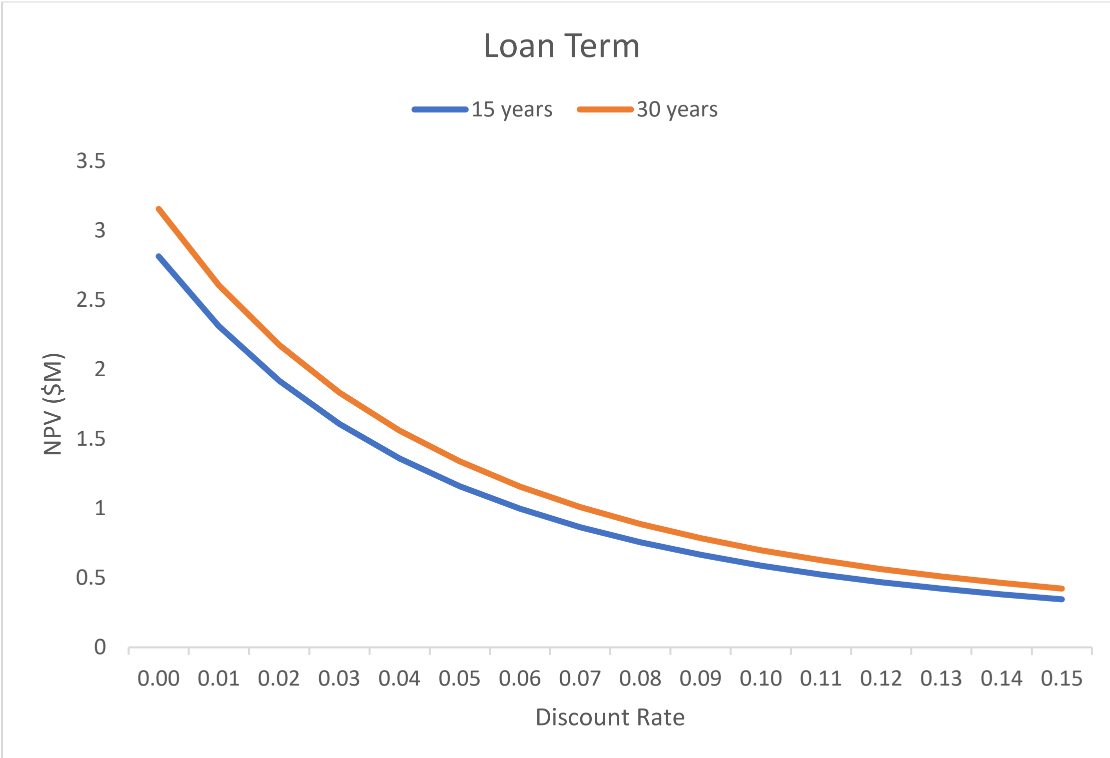


Figure 31: Scenario A2 Loan Term

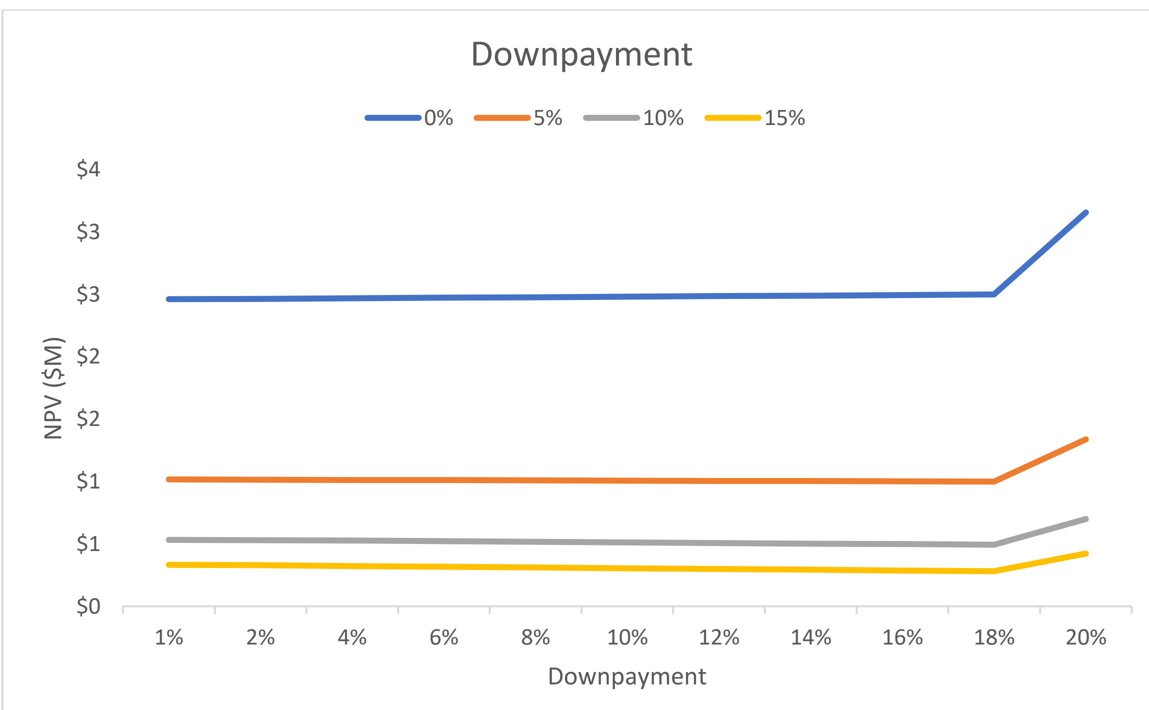


Figure 32: Scenario A2 Downpayment

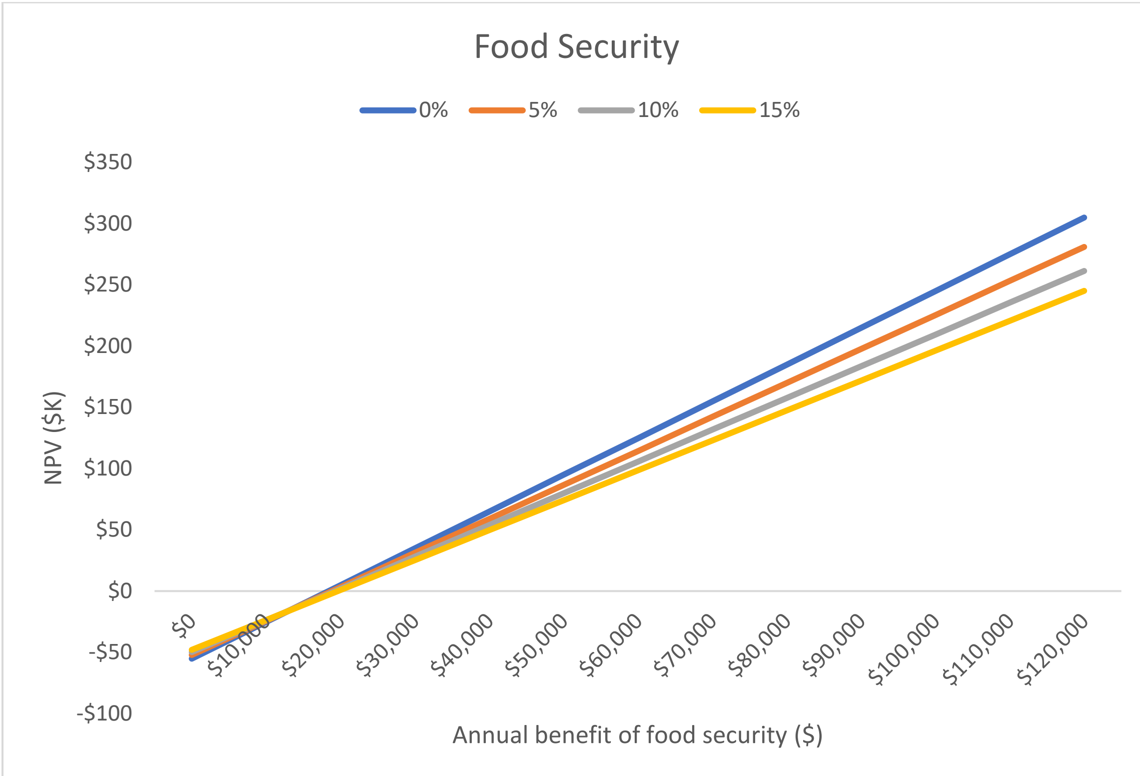


Figure 33: Scenario B2 Food Security

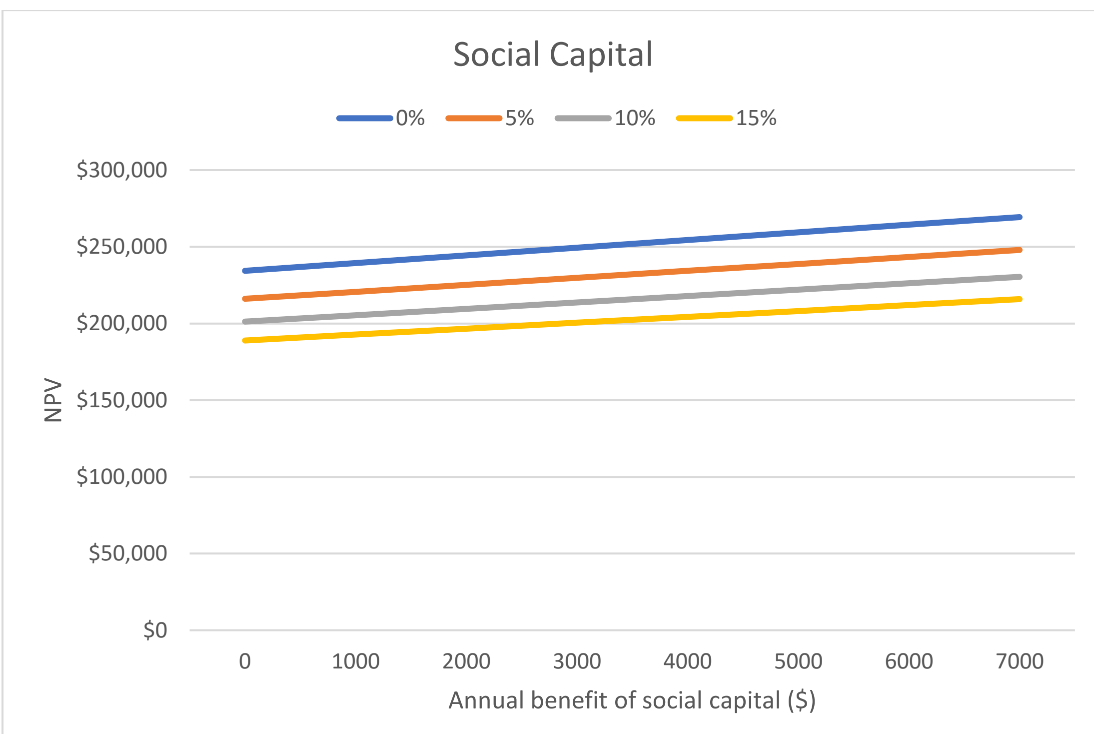


Figure 34: Scenario B2 Social Capital

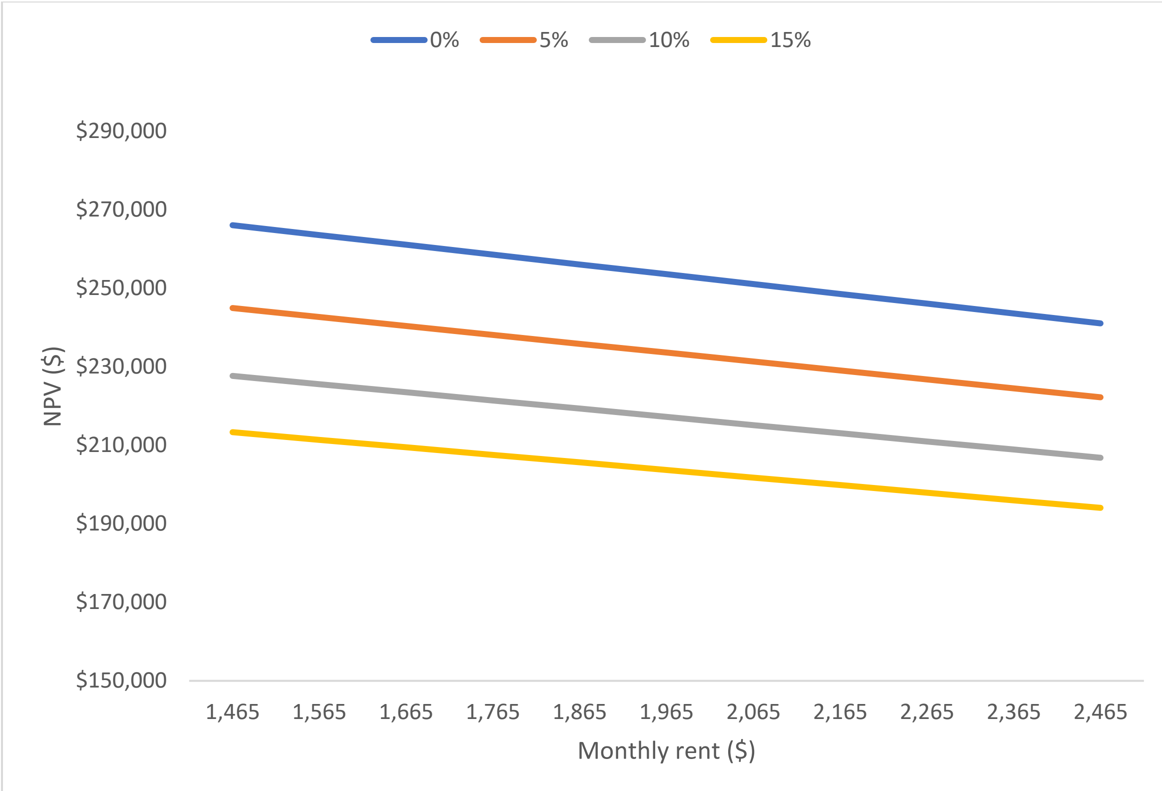


Figure 35: Scenario B2 Rent

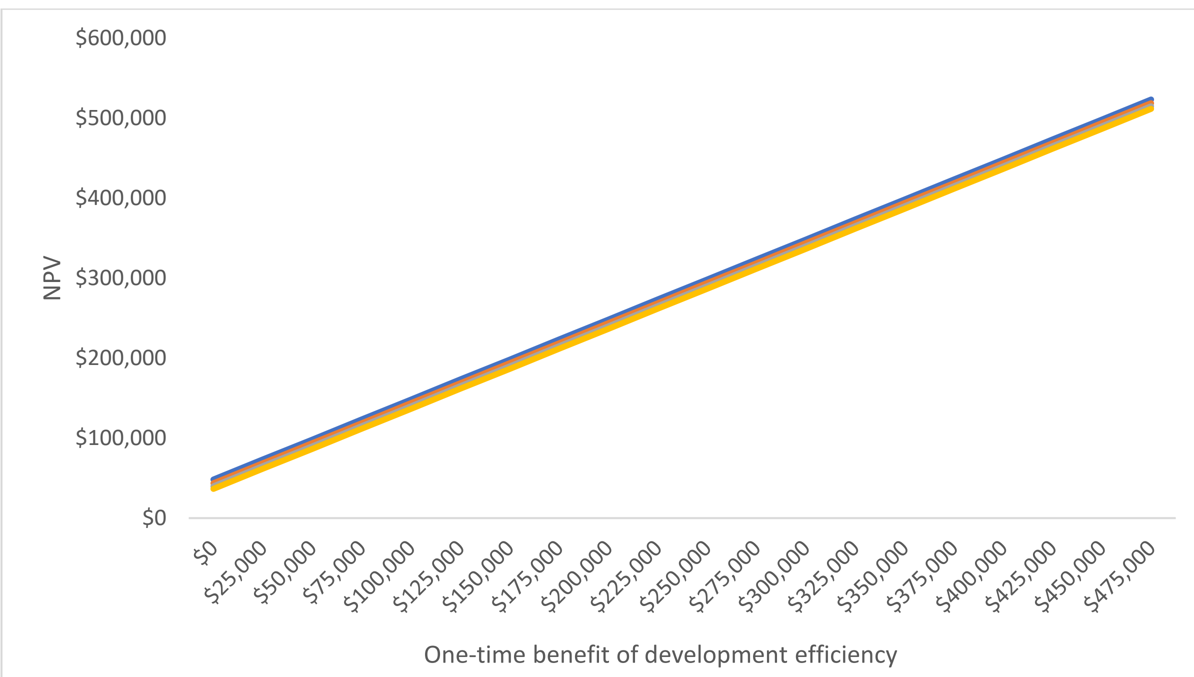


Figure 36: Scenario B2 Development Efficiency

Figure 37: Scenario B2 Taxes

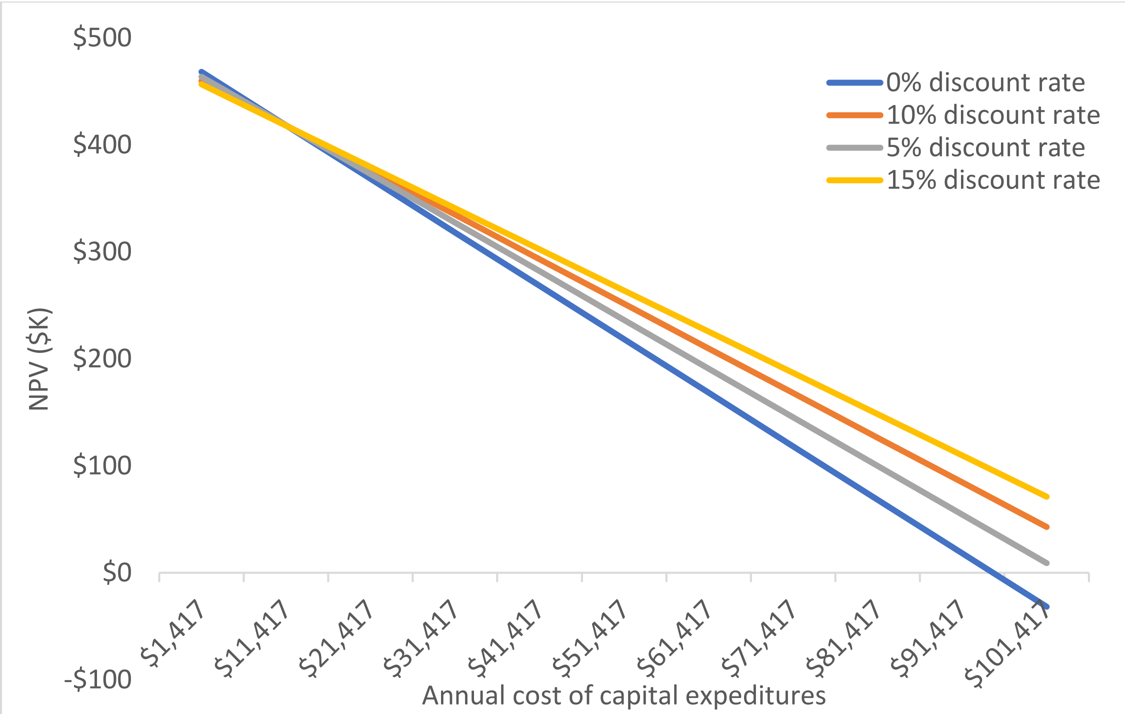


Figure 38: Scenario B2 Capital Expenditures

Quantitative, Non-Monetary Assessment of Outcomes and Values

The monetary value of an impact may not be readily available as was the case for the “energy needs” consequence. This consequence was estimated using MAUT described in Section 4.2.2, and is an example of non-monetary quantitative assessment of multiple building outcomes. The “energy needs” consequence was characterized using energy-related benefits data from Amasyali & El-Gohary (2016) and Fuchs et al. (2004). Amasyali & El-Gohary (2016) collected the energy-related values and satisfaction levels of residential occupants in Arizona (AZ), Pennsylvania (PA), Illinois (IL), and in the overall population sample. Fuchs et al. (2004) captured the desired non-energy energy-related benefits for New Homes residents and builders/contractors.

The results in Table 14 highlighted Arizonans’ strong preference for thermal comfort conditions during the winter, and Pennsylvanians’ and Illinoisans’ preferences for indoor air quality and visual comfort conditions also reflected in the overall population results. The results in Table 15 emphasized the New Homes residents’ strong preference for personal satisfaction. Contrarily, the builders and contractors emphasized resident comfort. However, comfort and resident satisfaction had the second-highest utility for residents and builders/contractors, respectively. Cost-effectiveness analyses could be a complementary approach to assessing the building value for multiple stakeholders and attribute and consequence tradeoffs if costs are known.

Table 14: Energy Needs MAUT

Location	**Attributes**	**Characteristics**	**Analysis**				**Sensitivity Analysis**
			Attractiveness Rating Scale	Importance Rating Scale	Weights	Single-attribute utility	Single-attribute utility
AZ	comfort conditions	thermal comfort in winter	4.82	4.84	0.14	**0.68**	**0.60**
	comfort conditions	thermal comfort in summer	4.51	0	0.00	0.00	0.56
	comfort conditions	visual comfort	4.7	4.73	0.14	0.65	0.59
	indoor air quality		4.61	4.96	0.15	0.67	0.58
	personal productivity		0	4.77	0.14	0.00	0.00
	health		0	5.18	0.15	0.00	0.00
	environmental protection		4.48	4.53	0.13	0.60	0.56
	energy cost savings		4.29	5.07	0.15	0.64	0.54
PA	comfort conditions	thermal comfort in winter	4.4	4.98	0.14	0.64	0.55
	comfort conditions	thermal comfort in summer	4.54	0	0.00	0.00	0.57
	comfort conditions	visual comfort	4.67	4.76	0.14	0.64	**0.58**
	indoor air quality		4.67	4.96	0.14	**0.67**	**0.58**
	personal productivity		0	4.84	0.14	0.00	0.00
	health		0	5.3	0.15	0.00	0.00
	environmental protection		4.31	4.59	0.13	0.57	0.54
	energy cost savings		4.31	5.06	0.15	0.63	0.54

Table 14 continued

IL	thermal comfort in winter	4.62	5.02	0.14	0.66	0.58
	thermal comfort in summer	4.56	0	0.00	0.00	0.57
	visual comfort	4.73	4.9	0.14	0.66	**0.59**
	indoor air quality	4.62	5.08	0.15	**0.67**	0.58
	personal productivity	0	4.88	0.14	0.00	0.00
	health	0	5.37	0.15	0.00	0.00
	environmental protection	4.44	4.66	0.13	0.59	0.56
	energy cost savings	4.27	5.08	0.15	0.62	0.53
Overall	thermal comfort in winter	4.61	4.95	0.14	0.66	0.58
	thermal comfort in summer	4.54	0	0.00	0.00	0.57
	visual comfort	4.7	4.8	0.14	0.65	**0.59**
	indoor air quality	4.63	5	0.14	**0.67**	0.58
	personal productivity	0	4.83	0.14	0.00	0.00
	health	0	5.28	0.15	0.00	0.00
	environmental protection	4.4	4.59	0.13	0.59	0.55
	energy cost savings	4.29	5.07	0.15	0.63	0.54

Table 15: Energy Needs MAUT (Note: separate builder/contractor criteria differences are on the right)

	New Homes Residents Analysis				Builders and Contractors Analysis			
	Attractiveness rating scale	Weight	Single-attribute utility	Sensitivity Analysis	Attractiveness rating scale	Weight	Single-attribute utility	Sensitivity Analysis
Equipment maintenance costs	2	7%	0.14	0.14	1.61	6%	0.10	0.12
Appliance performance	1.7	10%	0.17	0.12	3.11	11%	0.34	0.22
Appliance/equipment lifetimes	1.5	6%	0.09	0.11	2.14	8%	0.17	0.15
Personal/resident satisfaction	3.2	12%	**0.38**	**0.23**	3.36	12%	0.40	0.24
Comfort/resident comfort	3	11%	0.33	0.21	3.61	13%	**0.47**	**0.26**
Building aesthetics/appearance	1.7	7%	0.12	0.12	1.5	6%	0.09	0.11
Noise levels	1.7	6%	0.10	0.12	-1.64	-6%	0.10	-0.12
Building safety	1.7	6%	0.10	0.12	2.97	11%	0.33	0.21
Lighting/quality of light	1.2	5%	0.06	0.09	1.69	6%	0.10	0.12
Ease of selling the home	2.9	10%	0.29	0.21	3.33	12%	0.40	0.24
Ability to stay in their home because energy bills are too high	1.1	5%	0.06	0.08	2.58	10%	0.26	0.18
Doing good for the environment	3.1	10%	0.31	0.22	3.11	11%	0.34	0.22
Number of sick days lost from work	0.7	3%	0.02	0.05	2.17	8%	0.17	0.16
Number of calls to utility regarding bill issues/other	0.6	2%	0.01	0.04	0.81	3%	0.02	0.06

6. ECOSYSTEM LEVERS FOR ENHANCED PERFORMANCE

Innovative business models may enable the building ecosystem to deliver effective buildings. Recall, business models are mechanisms for entities to identify, create, capture, convey, deliver, protect, sustain, and manage value (Liu et al., 2020). Under current design and build models, the realization of intangible building benefits and optimized building outcomes require a fully integrated building owner. The opportunity exists for the building to meet multiple stakeholder objectives and improve their overall well-being if monetizable intangible benefits and preferred outcomes are realized and chapter 5 quantifies this potential. New business models may be derived from new combinations of new levers (e.g., business model components), or new whole models borne from applying BM fundamentals from other industries. In chapter 6, the former approach is applied to describe potential paths for revenue sources to optimize the building value. It is important to note as no single entity has the scope to deliver an integrated solution to capture and optimize the building value; only revenue-generating business levers that may be pulled by residential real estate players (i.e., the building ecosystem) to realize optimal outcomes were explored. Potential levers for residential real estate cases to create, capture, deliver newly identified value (e.g., the outcomes in chapter 5) have been inspired by different business model components of Cigna's and the Massachusetts DOT's I-91 viaduct construction models. The BM components are described in Table 16. These BMs may be pursuable, comprehensive, socio-temporal strategies to create, deliver, and capture the building value.

Table 16: Evaluated business model components and descriptions

Identify value	• Potential business opportunities characterized by consumer benefits and needs • X-axis - customer groups • Y-axis - value categorization
Create value	• An entity's actualization of products and services • X-axis - role companies play in the market • Y-axis - utilized assets
Capture value	• Revenue generation model • Categorized by payment mechanism and pricing strategy
Deliver value	• Act of purchase and obtaining an offering • Categorized by sales channel and delivery channel and criteria

Business levers for change were systematically explored using the methodology outlined in section 4.3 and mapped in Figure 39 below. Recall, ten residential real estate industry cases and two analogous cases were selected (step 1 in Figure 39) and deconstructed (step 2 in Figure 39) into business model components. Potential prototype outcomes-centered business model levers were generated, and their feasibility were assessed in step 3. First, the deconstructed BM representing the current state of practice of the residential real estate industry was summarized as single case analyses in A1.11. Then, cross-case analyses of residential real estate companies' mechanisms to create, identify, capture, and deliver value recognized business model similarities, and synergies that influence building performance and opportunities for innovation. After, Cigna and the I-91 viaduct cases were deconstructed for ideation inputs into prototype outcomes-centered business models in Section 6.2. On the former, the analogous inputs to create and capture value between Cigna and relevant residential real estate business practices are presented in Tables 23-31. Cigna's business terminology was translated to the residential building/real estate context in Table 20 to aid in prototyping manufacturing outcomes through new manufacturing, value-added, aggregating service models, physical asset distribution models, and financial and intangible asset manufacturing models in Section 6.3. The feasibility of these new model levers are discussed in Section 6.3. On the latter, the analogous inputs to create and capture value between the I-91 viaduct and relevant residential real estate business practices are presented in Table 32. A prototype to translate manufacturing outcomes through manufactured physical assets was not necessary as both cases are centered on physical assets.

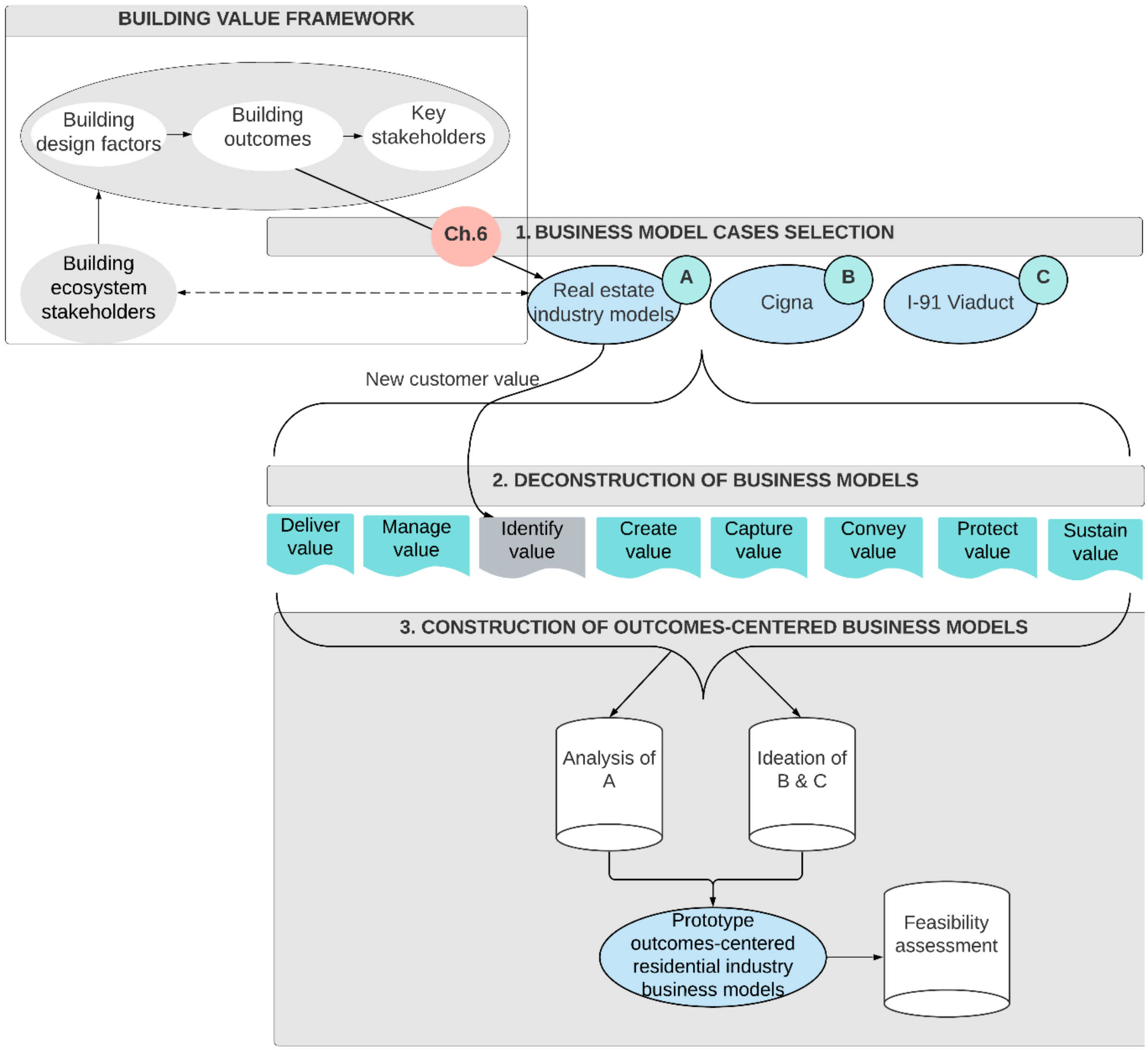


Figure 39: Conceptual map of business model innovation study

6.1 Cross-Case Analysis

The ten residential real estate cases and Cigna's value creation components are illustrated in Tables 17-20. The type of value offered to customers (i.e., identify value) may be economic, experiential, functional in Table 17. Customer segments are characterized by demographics, psychographics, need-based or job-based. Companies create value from different asset types as shown in Table 18, capture value through pricing (Table 19) and payment structures (Table 19), and deliver value (Table 20) to customers.

Create

All the real estate companies studied: 1) create value by manufacturing services, 2) provide functional value to job-based customer groups, 3) capture value in the form of instant, single payments. Eight companies create value from lending financial assets; five of them lend physical assets as well. All eight companies capture value from instant, single payments, five of them capture value using time-based subscription models and delayed single payments separately. Six of ten create value from manufacturing physical assets and services simultaneously. These six companies 1) capture value from instant, single payments, 2) deliver value using direct high and low-engagement strategies. Nine companies create value from physical assets, and seven of the nine concurrently create value from financial assets and services. Separately, three of the four companies that create value from human assets also create value from intangible assets, and two of them capture value from knowledge/content/data creation. Realogy and AECOM manufacture both intangible assets and knowledge/content/data creation. Two of the ten companies - AECOM and JLL - have performance-based metrics to indicate their monetization of outcomes. Neither company captures value using installments. Both companies use direct, low-engagement strategies to deliver value timely, accurately, and comfortably; and direct high-engagement methods to deliver value accurately.

Identify

Four companies deliver functional value to demographic-based groups; three offered either economic or experiential value to complement functional value. Only four of the ten companies offer more than functional value to job-based groups. Seven companies offer functional value to need-based groups. Three of those seven companies provided two additional value forms (i.e., economic and experiential or economic and emotional), and five of those seven offered at least one other value form. Three companies offer either economic or experiential value to psychographic customers. Zillow is the only company to provide social value to customers. Zillow is the only company that produced emotional value for customers. Seven of the ten companies offer functional value to both job-based and need-based groups. Two of the ten companies served functional value to both job-based and demographic-based groups. Realogy is the only company to offer functional value across all three groups. Seven companies offered experiential value; three to job-based groups, three to demographic-based groups, two to psychographic groups, one to demographic groups. Two companies proposed experiential value to more than one group. Five companies presented economic value to customers; only one to job-based groups, one to psychographic groups, two to demographic groups, and three to need-based groups.

Capture

Realogy is the only company to capture value using continuous payments of installments. Seven companies captured value using continuous payments based on usage; four exclusively use model-based pricing, three use cost-based pricing, one uses value-based pricing along with cost-based pricing. Six companies capture value in the form of delayed, single payments across the pricing method spectrum. Six of the ten companies use value-based pricing methods to capture instant, single payments. Only three companies exclusively use one pricing model for this payment structure; the other seven used multiple techniques to price instant, single payments. Realogy exclusively used model-based pricing for instant, single payments. JLL and AECOM exclusively use value-based pricing for instant, single payments. Seven of the ten companies captured value in the form of time-based subscription models. Only one company, DRHorton, exclusively used one pricing model for this payment structure (i.e., market-based pricing). AECOM and Howard Hughes are the only two of the ten companies that captured value from volume-based subscription models; one uses cost-based pricing and the other model-based.

Deliver

All ten companies utilized direct engagement – high and low – strategies, and eight of the ten prioritized comfort for the customer. Seven of the ten speedily delivered this value for the customer. Three companies used indirect engagement strategies to provide customer value; two use high engagement, and one employs low. Only four companies use pick-up strategies to engage with customers across both affiliated and non-affiliated facilities. Three companies prioritized accuracy, and two companies prioritized security in their value delivery. One of the eight companies that delivered on the measure of comfort also employed an indirect engagement strategy.

Table 17: Identify value

	Demographic group	**Psychographic group**	**Need group**	**Job group**
AECOM				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
AvalonBay Communities				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Cherry Hill				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Cigna				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
DRHorton				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				

Table 17 continued

	Demographic group	Psychographic group	Need group	Job group
Howard Hughes				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Jones Lang LaSalle, Inc.				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Realogy				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Vornado				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Welltower				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				
Zillow Group				
Economic value - High				
Emotional value - High				
Experiential value - High				
Experiential value - Low				
Functional value - High				
Social value - High				

Table 18: Create value

	Designer	Manufacturer	Distributor	Lender	Adder	Broker	Connector	Aggregator
AECOM								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
AvalonBay Communities								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
Cherry Hill								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								

Table 18 continued

	Designer	Manufacturer	Distributor	Lender	Adder	Broker	Connector	Aggregator
AECOM								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
AvalonBay Communities								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
Cherry Hill								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								

Table 18 continued

Cigna								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
DRHorton								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
Howard Hughes								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								

Table 18 continued

Jones Lang LaSalle, Inc.								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
Realogy								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service **Vornado**								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								

Table 18 continued

Welltower								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								
Zillow Group								
Financial asset								
Human asset								
Intangible asset								
Knowledge/content/data								
Outcome								
Physical asset								
Relationship								
Service								

Table 19: Capture value

Pricing Mechanism	Cost-based					Model-based							Value-based					Market-based					Unknown		
Payment Structure	Continuous payment / usage	Single payment / delayed	Single payment / instant	Subscription / time	Subscription / volume	Continuous payment / installments	Continuous payment / usage	Single payment / delayed	Single payment / instant	Subscription / time	Subscription / volume	Unknown payment mechanism	Continuous payment / usage	Single payment / delayed	Single payment / instant	Subscription / time	Unknown payment mechanism	Continuous payment / installments	Continuous payment / usage	Single payment / delayed	Single payment / instant	Subscription / time	Single payment / delayed	Single payment / instant	Subscription / time
AECOM	■	■			■									■	■										
AvalonBay	■		■	■				■	■							■									
Cherry Hill							■														■			■	
Cigna			■			■	■	■	■	■								■							
DRHorton									■												■	■			
Howard Hughes			■	■						■	■				■									■	■
Jones Lang LaSalle, Inc.	■			■						■			■	■	■	■	■						■		
Realogy		■				■	■	■	■																
Vornado			■	■								■			■	■									
Welltower							■								■	■				■	■	■		■	
Zillow Group							■	■	■	■					■	■					■				
MassDOT																			■						

Table 20: Deliver value

Sales Channel	Direct - high-engagement	Direct - low engagement	Indirect - high-engagement	Direct - high-engagement	Indirect - high-engagement	Direct - high-engagement	Indirect - high-engagement	Direct - low engagement	Direct - high-engagement	Indirect - high-engagement	Direct - low engagement	Direct - high-engagement	Indirect - high-engagement	Direct - low engagement	Direct - high-engagement	Indirect - high-engagement	Direct - low engagement
Distribution Channel	Pick-up at an affiliated facility			Pick-up at a non-affiliated facility		Delivery - Speed			Delivery - Accuracy			Delivery - Security			Delivery - Comfort		
AECOM						■		■	■		■						■
AvalonBay						■									■		■
Cherry Hill						■		■									
Cigna					■		■	■	■	■			■		■	■	
DRHorton	■											■	■				■
Howard Hughes	■			■		■									■		■
Jones Lang LaSalle, Inc.								■	■	■	■				■	■	■
Realogy	■							■									■
Vornado															■		■
Welltower																	
Zillow Group						■		■	■		■	■			■		■
MassDOT	■	■															

6.2 Ideation of Analogous Business Models

Ideation of Cigna

Cigna Corporation is taxed as a C-Corporation; it is a Delaware corporation with principal executive offices in Connecticut (Cigna Corporation, 2020). The Company may have a decentralized organizational structure operating in over 30 countries or a divisional structure due to numerous subsidiaries. The company will be abbreviated as Cigna for the remainder of the text. As shown in Table 21, Cigna created value from manufacturing, aggregating, and adding value to services, distributing physical assets, and manufacturing financial and intangible assets.

Cigna primarily captured revenue from Pharmacy products, Integrated Medical premiums, International Markets premiums, and service fees. Revenues for dispensing prescription drugs are received as an instant, single payment. Following a cost-based pricing model, the price of prescription drugs dispensed at pharmacies was the ingredient cost and dispensing fee (including the customer copayment and any associated service fees). Home delivery and specialty pharmacy dispensing revenue followed model-based pricing based on "net of reserves for discounts and contractual allowances estimated based on historical experience" (Cigna Corporation, 2020). Premiums for group life, accident and health insurance, and managed care coverages are recognized pro-rata basis over contract period (includes guaranteed cost) for Group Disability and Other, Integrated Medical, International Markets' Global Health Care, Local Health care (guaranteed cost only).

Similarly, experience-rated premiums for group life, accident, and health insurance and managed care coverages are recognized pro-rata over the contract period for Group Disability and Other, Integrated Medical, and International Markets Global Health Care segments. These premiums are priced from the model and recognized as continuous payment of installments. Premiums for individual life, accident and supplemental health insurance and annuity products, and fees for clinical solutions and health benefit management services at contracted rates for ASO arrangements mentioned previously can also be billed monthly based on current membership following model-based pricing received as time-based subscription payments. The Medicare Advantage plans and Medicare Part D product revenue in Integrated Medical were recognized ratably over the contract period as a delayed single payment. Their model-based pricing included customer demographics and wellness. Cigna received continuous payments based on usage and priced by models in several segments. Payment for ASO arrangements in the Group Disability and Other, Integrated Medical, International Markets' Global Health Care segments are fee-for-service clinical solutions, and health benefit management services are contracted rates billed monthly based on utilization with deferred revenue for performance guarantees based on expected value method. Universal life and investment-related products' administrative fees are assessed against the policyholder's balance in the Group Disability and Other and International Markets' Supplemental Health, Life, and Accident Insurance. Pharmacy benefit management and claims administration benefit design and formulary consultation services' contract rates are recognized periodically or as services are provided (i.e., based on the volume of claims processed). Integrated pharmacy fees were recognized periodically or as services were provided. Health benefit management solutions were collected as per-member-per-month fees or per-claim fees. Revenue from investment income of universal life and investment-related products in the Group Disability and Other, International Markets' Supplemental Health, Life and Accident Insurance segments were assumed to be continuous installment payments priced based on the market.

The Health Services segment delivered value through direct and indirect engagement methods. The Health Services segment used direct, high engagement methods to deliver value on measures of accuracy and comfort. Order processing pharmacies, specialty home delivery pharmacies, order processing at home delivery pharmacies, several non-dispensing prescription processing facilities, customer contact centers, patient contact centers, and automated home delivery dispensing pharmacies were examples of how this segment delivers value on measures of accuracy and speed. As part of their Pharmacy Dispensing products/services, the home delivery pharmacy services were more accurate than retail pharmacies and provide more convenient access to maintenance medications. Direct, low engagement through online communication and real-time processing of prescription drug claims with all in-network retail pharmacies enabled quick value delivery by the Supply Chain Administration and Management Retail Network Pharmacy Administration products/services. The Health Services segment employs indirect engagement to deliver value on measures of speed and security. Examples of speedily delivery include: 1) Provider Services' overnight shipping of products for delivery in the U.S., 2) Pharmacy Dispensing' real-time electronic review of pharmacy claim submissions of prescription drugs as the Drug Utilization Review program website. Also, the Health Services segment delivers value on the measure of security, or in this context, safety. This program's website, and pharmacy claim submissions are reviewed in real-time for health and safety to monitor issues and alert the dispensing pharmacy. Prescribers are sent opt-in client enrollment programs about potential therapy concerns after the initial claim is received. The secure, indirect, low-engagement delivery of value happens at non-affiliated facilities through the Retail Network Pharmacy Administration. When customers visit a network pharmacy, the pharmacy sends customer, prescriber, and prescription information through Cigna systems in an industry-standard format. These systems process claims and responds to pharmacies with relevant information to process the prescription. Sales representatives distribute products/services to clients, insurance companies, HMOs, and third-party administrators deliver value with a backdrop of comfort in a direct high-engagement manner in the Integrated Medical segment. Value delivery for the Government client of this segment focuses on expedient, direct, low-engagement as Medicare Advantage Plans use timely and transparent data sharing. The Integrated Medical segment's Connected Care Strategy highlights their pledge to deliver value in an exact form in an indirect high-engagement fashion at non-affiliated facilities; "*customers have access to the right care and in the preferred and appropriate setting at the right time*."

Each segment conveyed value differently. The Group Disability and Other segment convey value through direct push promotion of products/services from in-person contact of sales representatives. Also, direct sales representatives advertise in group selling venues as an indirect push technique to cultivate a customer relationship. Both approaches may cultivate the customer relationship from awareness through consideration to conversion. Integrated Medical used sales representatives for direct, push promotion of products/services to clients and other parties through in-person contact and telephone to foster the customer relationship from awareness, to consideration, to conversion. Sales representatives distribute products/services on private exchanges, to insurance brokers and consultants as an indirect push advertising style to build awareness. This style extended to their advertising in group selling venues. The International Markets segment used an indirect, push advertising style to promote awareness among insurance brokers, agents, affinity, and bancassurance.

Partnerships across the pharmaceutical supply chain and health care system are key organizational resources to protecting value creation at Cigna. First, the Health Services utilized several organizational steps to anticipate and prevent disturbances to value creation from physical and financial assets. The Health Services' organizational practice holds contracts with other wholesalers to hedge against physical assets sourcing issues. Partnerships and service contracts were mechanisms employed to prevent disturbances to value created from physical assets. Health Services' entered non-exclusive contracts with retail pharmacies. Specialty pharmacy services within this segment offered custom programs for biopharmaceutical manufacturers to strengthen partnerships. Similarly, Provider Services was a contracted supplier with most major group purchasing organizations. The Supply Chain Administration and Management's Retail Network Pharmacy Administration managed networks of pharmacies customized for or under direct contract with specific clients and have contracted with pharmacy provider networks to comply with the Center for Medicare and Medicaid services. The Health Benefit Management Services prevented disruption to value creation from financial assets by legal means when entering contracts with health plan payors. On the other hand, their organizational practice to nurtured vital relationships with clients, customers, providers, clinics, hospitals, and payors prevents financial asset value creation disruptions.

Cigna employed special personnel and knowledge sharing as an organizational means to protect human asset value creation. Specialty trained clinicians provide specialty pharmacy services in Pharmacy Dispensing. A formulary consulting team of pharmacists and financial analysts supports client formulary decisions, benefit design consultation, and utilization management programs.

The Integrated Medical segment used organizational tactics to protect intangible assets, human assets, and physical assets. As a Company, technology and data analytics protect against anticipated disruptions of value creation. Their teams conduct research and analysis to "*close care gaps, optimize treatment and improve outcomes*," and "*design affordable benefit plans and services, serve customers and clients, and improve care costs and health outcomes*." Talent contracts and strategic alliances with health care providers prevent disturbances to value creation from human assets. Broad network access for Medicare drug products and cost-containment programs with contracted third-party vendors prevent interruption of value creation from physical assets.

The Group Disability and Other and International Markets segments use organizational tools to absorb financial asset value creation disturbances. The Group Disability and Other segment purchases reinsurance from unaffiliated reinsurers and prevents disturbances through contract agreements. The International Markets segment employs retention risk management as a protective measure.

As a Company, Cigna legally protects value from intangible assets through mechanisms with more than 190 U.S. patents. Strategic technological innovation through Cigna Technology Services and the "*timely, rigorous and objective research and analysis*" of analytics protects value created from intangible assets. Intangible and human assets were crucial to protecting value created from analytics. Extensive data expertise in data management, business analysis, intelligence, data science, and ongoing investments in talent development, analytic, and big data technologies protect value creation (Cigna Corporation, 2020). Third-party partnerships secure controls to guard sensitive client and customer information.

Cigna maintained its competitive advantage by maintaining stability, efficiency, differentiation, quality, experience, agility, and reach primarily to deliver value for stakeholders within its ecosystem. Their long-term customer contracts of 1-3 years or up to 5 years in the Group Disability and Other segment is an example of Cigna's advantage of stability. The focus on cost control, pricing, supply chain efficiency hallmark Cigna's competitive advantage on efficiency. Their proficiency in achieving cost affordability, drug distribution efficiency, and cost management for the pharmacy's benefit endorses their ability to capture longitudinal value. For example, "*leveraging purchasing volume to deliver discounts drive risk-sharing and value-based care across the pharmaceutical supply chain*." Health Services' evaluation of medicine value, price, and efficacy in terms of cost-effectiveness. Cost control is exemplified in the orderly underwriting, pricing, and investment strategies in the Group Disability and Other segment. Also, the Pharmacy Dispensing home delivery pharmacy services control the client's drug costs through operating efficiencies.

An example of Cigna's differentiation is its balance of stakeholder needs. For example, the Group Disability and Other products promote employee health, wellness, and productivity through medical, specialty, and integrated disability offerings. On the same note, their disability absence management model lessens the overall costs to employers. Another example is in the Integrated Medical segment. Its Connected Care strategy of the Integrated Medical segment endorses its ability to capture and distribute longitudinal value. This strategy "*connects customers and providers through aligned health goals, engages customers in their health, collaborates with providers to help them improve their performance, incentives and actionable information to enable* *better decisions and outcomes*." Another example includes their Medicare Advantage business value-based physician engagement model, where physicians share financial outcomes with Cigna. The extensive Integrated Medical solution portfolio was customer-centric. Their integrated benefit solutions "*delivers value for customers, clients, and partners*." Health Services' differentiates itself by balancing low-cost, clinically effective medication brands and generics. This differentiator was paralleled in their home delivery and specialty services which affords cost savings and enhanced, specialized clinical care for clients and customers. The International Markets' differentiator is "*financial security, affordable coverage, range of health and protection-related solutions to meet the needs of the growing middle class and globally mobile*." Their locally-sourced talent oversees their locally-licensed and compliant solutions. Overall, Cigna's key differentiator is its data and analytics capabilities, enabling "*affordability, simplicity, predictability, and growth across all of the Company's business platform*s."

Quality was a competitive advantage for Cigna. Their commitment to "*best-in-class quality of care*" is supported by their goal of improved health outcomes and patient satisfaction. For example, the Health Services segment bolsters high customer satisfaction. Similarly, the Integrated Medical segment has a hospital quality program where value-based reimbursement arrangements are connected to quality metrics, and physician engagement models appreciate service value over volume. The International Markets' segment maintains a broad, global provider network for sizeable access to quality, affordable care.

Cigna's emphasis on the stakeholder experience is evident in their business strategy:

> "Go Deeper: Expand and deepen our customer, client, and partner relationships and create depth in targeted sub-segments and geographies
>
> Go Local: To ensure our solution suite and services meet customer, client and partner needs at a local market level
>
> Go Beyond: To innovate and further differentiate our businesses, the experiences we deliver, and our overall social impact."

Moreover, the Health Services division underscores customer service with their "*specialized clinical care*." This sentiment is echoed in the Integrated Medical "*commitment to* *highest quality health outcomes and customer experiences*," and International Markets pledge to meet the needs of the expanding globally mobile and middle class.

Cigna's reach and agility are competitive advantages; its broad customer base is matched with wide-ranging geographical coverage and depth in targeted sub-segments and geographies. For example, the Health Services pharmacy dispensing and provider services' distribution capabilities are nationwide, and the home delivery dispensing services were available in 4 states. Also, the Integrated Medical Accountable Care Program has 3 million customers across 34 states, and the Specialist Programs has nationwide arrangements with different types of specialist groups. The Integrated Medical Government segment stand-alone prescription drug products had broad network access "*intended to promote wellness and affordability for our eligible beneficiaries*." The International Markets segment operates in over 30 countries/jurisdictions. The Health Services' advantage of agility was indicated in their ability to fulfill orders quickly. For example, they can procure a drug, not in inventory within one business day.

Lastly, Cigna focused on process innovation by selecting solutions that improve patient outcomes and control costs using predictive analytics and insights in the International Markets segment for product and service innovation, direct-to-consumer distribution competencies, and the Integrated Medical segment for health care delivery solutions.

Cigna "buys" clinical talent to bolster operational support and personal and specialized customer care. For example, the pharmacy benefit management services health care providers (e.g., pharmacists and physicians) "identify emerging medication-related safety issues, alert physicians, clients, and customers (as appropriate); provide drug information services; manage formulary; and develop utilization management, safety (drug utilization review) and other clinical interventions" (Cigna Corporation, 2020). Also, the pharmacy benefit management and health benefit management services staff were highly trained health care professionals who specialize in care for customers with select chronic and complex conditions. Similarly, their Therapeutic Resource Centers are staffed with specialist pharmacists, nurses, and other clinicians.

The Company builds partnerships between in-house sales and account management teams, clinical pharmacy managers and benefits analysis consultants, and client service representatives were essential to market and sell pharmacy benefit management solutions (Cigna Corporation, 2020). The Company borrows talent using contracts with health care providers in the Integrated Medical segment.

Cigna secures its supply of providers and pharmaceuticals to control costs on behalf of its customers, promote convenient access to products, and care through the management of national and regional networks. Also, Cigna's Connected Care strategy where Cigna "collaborates with providers to help them improve their performance, and offer incentives and actionable information to enable better decisions and outcomes." Their Supply Chain Administration and Management segment manages customized pharmacy networks for specific clients. For example, Cigna Specialty Products & Services employs third-party vendors for cost-containment programs. Likewise, Cigna negotiates discounted drug prices on behalf of customers with pharmacies to support their Health Services Retail Network Pharmacy Administration. Cigna contracts with compliant Center for Medicare and Medicaid Services ("CMS") access requirements for the federal Medicare Part D prescription drug program ("Medicare Part D") pharmacy provider networks. Cigna Health Services' sold brand-name, generic, and biopharmaceutical products for home delivery and specialty pharmacies. Out-of-stock drugs were often acquired from a supplier within one business day. These suppliers are generally manufacturers or authorized wholesalers. Their supply chain contracting and strategy teams "negotiate and manage pharmacy network contracts, pharmaceutical, and wholesaler purchasing contracts and manufacturer rebate contracts."

The Company "borrowed" facilities to deliver prescription drugs to customers. "Prescription drugs are dispensed primarily through networks of retail pharmacies, home delivery, and specialty drug fulfillment pharmacies" (Cigna Corporation, 2020). The Health Services segment maintained "eight order processing pharmacies, four high-volume automated home delivery dispensing pharmacies, seven specialty home delivery pharmacies, 38 specialty branch pharmacies, and eight patient contact centers. The Provider Services segment operated three distribution centers. Cigna operates condition-specific Therapeutic Resource Center facilities.

Table 21: Identified value provided to Cigna beneficiaries with demographic (bold), psychographic (plain), need (underlined), job (italicized)

Business segment	Functional value	Economic value	Experiential value
Group Disability and Other	**Multistate employers with 5,000 or more U.S.-based, full-time employees.** **Employers generally with 250 to 4,999 U.S.-based, full-time employees.** **Employers generally with up to 249 eligible employees** *Voluntary Products and Services - employees Personal Accident Insurance - employers and employees,* *Corporate-owned Life Insurance - corporations*		
Integrated Medical	<u>customers in need of health care</u>, *providers*	*Providers, independent practice associations*	<u>customers in need of health care</u>
Integrated Medical - Commercial	*Multistate employers with 5,000 or more U.S.-based, full-time employee - ASO funding solutions* *Employers generally with 500 to 4,999 U.S.-based, full-time employees. This segment also includes single-site employers with more than 5,000 employees and Taft-Hartley plans and other groups.- ASO, experience-rated and guaranteed cost insured funding solutions* *Employers generally with 51-499 eligible employees. - ASO with stop-loss insurance coverage and guaranteed cost insured funding solutions* *employers (also referred to as "clients") and their employees (also referred to as "customers") and other groups (i.e. unions)*		

Table 21 continued

Integrated Medical - Government		**Individual and Family plans, Medicare Advantage plans, Medicare Stand-Alone Prescription Drug products**	**Medicare Advantage plans, Medicare Supplement plans, Medicare Stand-Alone Prescription Drug products**
Integrated Medical -Specialty Products & Services	Dental Solutions - individual customers <u>Pharmacy Management - clients and customers, Consumer Health Engagement - customers covered under plans by Cigna or third-party administrators, Cost-Containment Programs – customers</u> *Global Health Care - multinational employers, intergovernmental and nongovernmental organizations*	Stop-Loss- self-insured clients	<u>customers</u>
International Markets	**Local Health Care - employers and individuals in specific countries where the products and services are purchased** <u>Supplemental Health, Life and Accident Insurance – individuals</u> Global Health Care - globally mobile individuals of multinational organizations *Global Health Care - multinational employers, intergovernmental and nongovernmental organizations*		

Table 21 continued

Health Services	Provider Services - contracted supplier with most major group purchasing organizations Supply Chain Administration and Management - Administration of Group Purchasing Organizations: participants *Clients: managed care organizations, health insurers, third-party administrators, employers, union-sponsored benefit plans, workers' compensation plans, government health programs, providers, clinics, hospitals and others* *Provider Services - directly to health care providers, clinics and hospitals in the United States for office or clinic administration* *Provider Services - third-party logistics provider for several pharmaceutical companies* *Health Services: Supply Chain Administration and Management - Benefits Design Consultation: clients* *Supply Chain Administration and Management - Drug Formulary Management: clients and assist customers, physicians* *Supply Chain Administration and Management - Administration of Group Purchasing Organizations - organizations and their participants*	*- Health Benefit Management Services: clients, commercial and government payors* *- Provider Services - office and clinic-based physicians who treat customers with chronic diseases and regularly order costly specialty pharmaceuticals* *- Clinical Solutions*	Patients connected to clients Health Benefit Management Services: patients

Ideation of MassDOT I-91 Viaduct Rehabilitation

As a manufacturer of physical assets, the Massachusetts Department of Transportation rehabilitated the Interstate 91 viaduct. Milone & MacBroom, Inc., & The Massachusetts Department of Transportation (2018) studied improving the impact of the physical structure on the surrounding community as part of the rehabilitation, positioning them as a manufacturer of outcomes. Practical transportation improvements to enhance mobility and safety, health and environmental effects, connectivity and accessibility, land use and economic development, community effects, and costs were studied. The viaduct as an offering provided functional, economic, and experiential value to the stakeholders recognized in the study. Stakeholders in the study included the local business community, elected and local officials, community groups and organizations, individuals, property owners, planning commissions, industry organizations, transit agencies, and railroad and transit agencies located in and around Springfield, West Springfield, Chicopee, Agawam, Holyoke, and Longmeadow (Milone & MacBroom, Inc., & The Massachusetts Department of Transportation, 2018). The I-91 viaduct customers are identified as a demographic group within the primary and regional study area. The physical area for potential physical transportation system improvements was the primary study area. The additional transportation paths that may be affected by these improvements are considered the regional study area.

The project value was conveyed as advertisements to the public to garner support, opinions and to gauge community satisfaction. Project information - study updates, meeting announcements - was sent electronically via e-blasts and posted on social media as a direct push advertising strategy; and the official project website as a direct pull advertising strategy. Public meetings were a component of their direct pull strategy and allowed the public to interact with the study team, ask questions, and provide feedback. Working group meetings of members from different stakeholder groups –responsible for providing input and communicating project outputs to their respective groups – was an indirect push advertising method to maintain buy-in. Project information and press releases through the local media are also part of an indirect push strategy of public outreach. The team coordinated general outreach efforts when necessary to avoid public confusion as part of their direct push strategy.

The I-91 Viaduct delivered value was at an affiliated facility (e.g., the viaduct) for the primary and regional study area stakeholders. The sales channel for tax collection likely follows a direct low engagement model. Contact with MassDOT can be in-person at an affiliated facility (direct high engagement), online through their official website (direct low engagement), or over the phone during typical business hours (direct high engagement).

How revenue may be captured under different development scenarios was generated from various revenue streams given the number of residential units and office, retail, and industrial square feet. The annual tax revenue to the City of Springfield was estimated from per-unit and per-square-foot valuations of a sample of existing properties multiplied by the millage rate. This payment structure is implicative of a continuous payment based on usage. The taxing authorities set the millage rate, and the property valuations are based on the local assessor's data, both indicative of market-based or model-based pricing.

MassDOT protected the value created by the I-91 Viaduct as a physical asset through organizational means such as regular maintenance and partnerships with stakeholders to anticipate and repairs to absorb any disturbances value. Service contracts with the construction contractor selected from the design-bid-build process prevent disturbances to value created by the physical asset. Market and economic environment studies like the publication studied (Milone & MacBroom, Inc., & The Massachusetts Department of Transportation, 2018). anticipates disturbances to the value creation of the Viaduct as a financial asset. The MassDOT is a government entity and works for the public interest; therefore, it was unnecessary to discuss its competitive advantage (i.e., measures to sustain value).

Residential buildings and the I-91 viaduct are physical assets; therefore, protoype models with terminology translation in the building context were unnecessary. Nonetheless, the business cases - AECOM, AvalonBay, DRHorton, Howard Hughes, JLL, and Vornado - that create value from manufacturing physical assets are listed in Table 32, along with how they capture value. These companies capture value from physical asset manufacturing as a single, instant payment, unlike the I-91 model, which captured value as a usage-based continuous payment. A change in payment structure may be necessary for these companies to manufacture outcomes through physical assets.

6.3 Prototyping of Analogous Business Levers

The specific residential real estate industry case levers to monetize optimal building outcomes such as new payment mechanisms and pricing strategies to manufacture outcomes through service manufacturing, service aggregation, as service adders, physical asset distributors, financial asset manufacturers, and intangible asset manufacturers are discussed. The residential real estate business model levers that may benefit from the change in BM components - capturing and customer value or segment gains– inspired from Cigna and MassDOT are summarized in Tables 23-32. Subsequently, the feasibility of these changes for residential real estate cases are described. Cigna's business terminology was translated to the residential building/real estate context in Table 22 to aid in the analogical reasoning. Outcome manufacturing levers for relevant cases are provided in Table 31, and may provide additional opportunities when coupled with other asset types.

Table 22: Translation of Cigna terminology to residential building context

Cigna terms	Analogous terms to residential building development and ownership
Claim	Request for covered loss or event
Clinical	Operational - relating to the observation and treatment of actual patients
Drug formulary – list of generic and brand names covered by a health plan	List of corrective physical building solutions covered by bldg care plan
Disease – a condition of the living animal or plant body or of one of its parts that impairs normal functioning and is typically manifested by distinguishing signs and symptom	Building output or housing condition that impairs human function
Disability	Limiting living conditions
Group health plan - an employee welfare benefit plan established or maintained by an employer or by an employee organization (such as a union), or both, that provides medical care for participants or their dependents directly or through insurance, reimbursement, or otherwise	Residential community plan - resident welfare benefit plan established or maintained by a resident organization or local government (e.g., payor) or both that sustain residences for residents directly through insurance, reimbursement, or otherwise
Health – general condition of the body	Status of residential building system performance
Health care	Residential building system sustainment - the provision of what is necessary for the health, welfare, maintenance, and protection of the residence, its occupants, and owners
Health care system	Residential building ecosystem - organization of people, institutions, and resources that deliver residential building system care services to meet the residential building system needs of target populations
Health plan - offers a wide range of health care services through a network of providers who agree to supply services to members	Residential building system plan offers a range of residential building system services/products to members. These services/products include the residential building inputs, activities, and outputs that yield optimal building outcomes/values.
Health benefits - The health care items or services covered under a health insurance plan	The benefits of residential building system performance are covered under a residential building system performance plan.

Table 22 continued

Network – social/professional systems of arrangements	The network would be professional arrangements, such as building service providers and technology suppliers and social arrangements.
Network performance - Network performance refers to measures of service quality of a network as seen by the customer	Network performance refers to service quality measures of a network as seen by the building owner and occupiers and may extend to other payors/participants.
Medical care	The effective building or living solutions ranging across asset types such as physical, service, and financial assets that affect occupant well-being
Patient	Occupant
Pharmaceuticals	Physical building solutions (e.g., equipment, utilities, furniture, electronics, lighting) were applied to fix the residential building system
Pharmacy - the art, practice, or profession of preparing, preserving, compounding, and dispensing medical drugs	Physical building solution provider
Pharmacy benefit manager - a third-party administrator of prescription drug programs. PBMs are primarily responsible for developing and maintaining the formulary, contracting with pharmacies, negotiating discounts and rebates with drug manufacturers, and processing and paying prescription drug claims	A third party to manage physical building solution providers and programs. Managers would be responsible for: • developing and maintaining the specifications and procedures of the appropriate physical building solutions covered by the plan, • contracting with physical building solution providers, • negotiating discounts and rebates with physical building solution providers, • processing and paying physical building solution claims.
Physicians	Building servicers
Policy	A contract between longitudinal stakeholders
Premium	Amount of money paid for a policy
Prescriber	Building servicers
Prescription drugs – therapeutic or corrective agents	Corrective physical building solutions/products

Levers for service manufacturers and service adders

Cigna's Health Services, Group Disability and Other, Integrated Medical (government and specialty products and services), and International Markets BM levers in Table 23 provide analogies for the residential real estate case BM levers for manufacturing outcomes through service manufacturing in Table 24. In these models, high-quality, cost-effective care through prescription drug utilization and cost management was provided through pharmacy benefit management services. Similarly, building service companies such as building management and maintenance services and title and mortgage servicers can offer sustainable, corrective solutions, either physical assets like effective physical or non-physical building solutions to deliver quality residential building system support. Residential building system plans would have offerings designed to balance affordability, choice, simplicity, and convenience for occupants with cost-effective options for payors.

Cigna's Health Services business inspires several potential business model innovation for the building space. First, residential building services resembling Cigna pharmacy benefit services should yield offerings to meet client needs - across care, service, and cost - and deliver better outcomes, higher customer satisfaction, and corrective physical building solutions/products. For example, service manufacturers can provide safe, accurate, and convenient access to effective, corrective physical building maintenance products by 1) managing client product costs through operating efficiencies, 2) operating non-dispensing processing facilities and customer contact centers for effective, corrective physical building maintenance products, similar to the home delivery pharmacy service model. Also, service manufacturers may provide a greater level of predictable, residential building system support and effective physical building solution management for customers with specialty product needs, custom programs for building technology manufacturers, and improved visibility and outcomes for payors through assets and capabilities by adopting the specialty pharmacy service model. Assets and capabilities include nationwide access to specially trained service providers, home servicers, reimbursement and customer assistance programs, and building technology services. Specialty corrective products may require frequent, measured adjustments; intense real-time monitoring, customer training, specialized product administration requirements, or products effective, physical building solutions limited to specific specialty retailers and distributors by manufacturers. Separately, service aggregators may benefit from the specialty service model and the home delivery pharmacy model. The home delivery pharmacy model may support their service coordination between building service providers and customers and procurement of highly cost-effective, physical corrective products that better adhere to effective building system behavior. Second, a parallel version of Cigna’s supply chain administration and management would facilitate supply chain administration and management for residential building system services. It would entail the administration of retail networks for effective, corrective physical building products, benefits design consultation, administration of group purchasing organizations, and solution formulary management. Third, the administration of retail networks would be the management of national and regional networks responsive to client preferences related to cost containment, the convenience of access for owners and occupiers, and network performance. The administration of retail networks for effective, corrective, physical building product and service retailers may be realized through contracting with product and service retailers of customer cost sources to receive offerings at discount prices negotiated to benefit the customer. The administration of retail networks may involve managing customized networks of building products retailers for or under direct contract with specific clients and contracting with product retailers compliant with government requirements. Maintaining real-time, online communication with retailers to process product/service claims may be an essential capability. For example, a network cost source (e.g., process corrective agent retailer/servicer) would send specific customer (e.g., occupant or owner), service provider, and corrective product information in an industry-standard format to Company A’s systems when a customer engages for help. Company A would process the claim and respond to the entity with the relevant information to process the protocols and rules for a corrective agent. Fourth, Company A may offer benefits design consultation with a model like Cigna’s benefits design consultation. It would entail consulting clients on how best to structure and leverage physical corrective solutions to meet plan objectives for affordable access to and safe and effective use of the corrective solutions people need to stay healthy, well, and achieve their values. Fifth, if Company A had an offering similar to Cigna’s administration of the group purchasing organization (e.g., Express Scripts), it would negotiate with manufacturers to buy pricing, fees, and formulary rebates to buy effective, physical buildings solutions on behalf of group purchasing organizations’ participants. It would also provide various administrative services to its participants, including management and reporting. Sixth, if Company A offered building solution formulary management, it would maintain lists of effective, physical buildings solutions with designations to determine coverage, customer out-ofpocket costs, and communicate plan preferences in competitive building solution categories. Physical building solution formulary management services establish formularies that assist service providers/suppliers to select operationally appropriate, cost-effective solutions and prioritize access, safety, and affordability for clients and customers. Standard formularies could be administered on clients' behalf of clients or customized. Standard formularies may be governed by a national board comprising a panel of in-practice building stakeholders, building service providers, and active practitioners/operators connected to physical building cost sources (e.g., building solution retailers, producers). This board would represent a variety of specialty backgrounds and settings, typically with major affiliations. The formulary recommendations of this committee would be based only on building solution safety and efficacy and not the cost, negotiated manufacturer discount, or rebate arrangements to ensure the operational recommendation is not affected by financial arrangements. Seventh, Company A would be fully compliant with building solutions deemed included or excluded from the formulary based on their assessment of safety and efficacy. A potential result of this model is operationally appropriate residential building system support, as in care provided promptly meeting professionally recognized standards of acceptable residential building sustain, delivered in the appropriate setting; and is the least costly of multiple, equally effective alternative interventions or diagnostic modalities. Eighth, Company A may provide integrated residential building system benefit management solutions focused on driving adherence to evidence-based guidelines, improving the quality of occupant outcomes, and reducing the cost of care for clients under a residential building system benefit management services model similar to Cigna's health benefits management model. This capability may be enabled through contracts with residential building system plans, residential and government payors to promote the appropriate use of residential building system services by the customers they serve. It may occur through capitated risk arrangements in certain instances. Company A assumes the financial obligation for the residential building system cost services provided to eligible customers covered by residential building system management programs. Last, corrective physical building solution claim adjudication may accompany their solution dispensing activities, similar to Cigna's drug claim adjudication service. Product claim processing for home delivery, specialty, or retail networks may be facilitated by integrating physical building product retailer network administration, benefit design consultation, utilization review, formulary management, and fulfillment services. Then use end-to-end adjudication services to administer payments to retail networks and bill benefit costs to clients.

The Integrated Medical Medicare segment provided a model for customers ages 65 years and older and connected to government-funded plans. A similar plan would give several effective physical building solution options, service, and information support. Stand-alone plans would provide more significant benefits; an effective, physical building product list tailored to an individual's specific needs and access to a broad network and value-added services intended to promote wellness and affordability. The companies who add value to services (see Table 29) may benefit from the model (also outlined in Table 27) as well. The Specialty Products & Services model may improve occupant engagement, cost-containment programs, behavioral and other aspects of the residential building system, building cost sources, effective physical product management, and stop-loss insurance. Customer residential building system engagement services would be covered under plans administered by insurance companies or third-party administrators, including an array of residential building system and impaired living management and wellness services. Case, specialty, and utilization management and a residential building system information line that may facilitate living management programs. Residential building system support advocacy program services include early intervention to remedy living conditions and an array of health and wellness coaching. Company A would administer incentives programs designed to encourage customers to engage in residential building system improvement activities. Cost-containment programs would be intended to contain the cost of covered residential building system services and supplies by reducing out-of-network utilization and costs, protect customers from balance billing and educate customers regarding the availability of lower-cost in-network services. In addition, under these programs, we negotiate discounts with out-of-network service providers, review provider bills, and recover overpayments. Company A would charge fees for providing or arranging for these services. Contracted third-party vendors may administer these programs. Behavioral residential building system case management would entail integrated occupant assistance programs and work/life programs; effective, physical building products; and customer activity limiting building interactions programs to facilitate customized, holistic care. The physical, effective building solution dispensing services and benefits could be combined with residential living offerings as an all-inclusive suite of physical, effective building solution management services available to clients and customers such as benefits management, specialty services, operational solutions, home delivery, and certain residential building system management services. Lastly, stop-loss insurance provides reimbursement for claims over a predetermined amount for individuals, the entire group, or both. Stop-loss insurance coverage may be offered to self-insured clients whose group residential building system plans are administered by Company A. Cigna's Integrated Medical specialty products and services model for stop-loss solutions may also be advantageous for financial asset manufacturers.

The International Markets' global health care products and services model may aid in stop-loss insurance would include stop-loss insurance, and administrative services for living conditions, physical building solutions, and limiting building conditions attentive to maintaining healthy and productive globally mobile occupants and payor offerings through guaranteed cost, experience-rated and administrative services only funding solutions. A translation of this model applied to financial assets may benefit financial asset manufacturers as well.

Cigna's Group Disability and Other model may propel solutions that help customers effectively manage the temporary loss of income and revenue, comprehensive and straightforward service plans to manage benefits or unexpected repairs, damages, displacements, and more serious impairments to living conditions. Specifically, the leave administrative solutions help customers manage income loss and provide coverage for paid leave. Adapting the voluntary services plan may provide building owners with managerial solutions designed to manage their building benefits program comprehensively. Also, a form of Cigna's voluntary offerings may include coverage for unexpected repairs, damages, displacements.

Levers for service aggregators and physical asset distributors

Complementary to the potential advantages of the Health Services' pharmacy dispensing scheme home delivery and specialty service schemes mentioned previously, service aggregators in Table 26 may benefit from model levers similar to the Health Services' provider services and the Integrated Medical participating provider network model levers in Table 25. On the former, Cigna's CuraScript SD is an example provider services model. It may position Company A as a specialty distributor of effective, physical solutions and residential living supplies directly to residential building system service providers for routine/preventative and severe care. The residential building system service providers may support customers with dire, impaired living conditions and regularly order costly specialty effective, physical solutions and residential living supplies. This model may position Company A 1) to offer competitive pricing on physical residential solutions as a contracted supplier with most major group purchasing organizations, and 2) to operate as a third-party logistics provider for several effective, physical solution companies by leveraging a distribution platform. Company A would need operational distribution centers and domestic overnight shipping capabilities. The distributors of physical assets in Table 29 may find this model – also in Table 27 - advantageous as well. On the latter, Company A's variation of Cigna's Integrated Medical's participating provider network model would provide owners and occupants with an extensive network of participating residential building system physical assets and service providers. Direct contracts with providers directly, contracting with third parties to access their provider networks and care management services, or cultivating strategic alliances with several regional managed care organizations to access their provider networks and discounts may support this effort. Plan offerings for aggregating these services may resemble Cigna's commercial *Managed Care Plans, PPO Plans, Consumer-Driven Products,* or government-funded Individual and Family Plans. *Managed Care Plans and PPO Plans.* PPO plans use meaningful cost-sharing incentives to encourage the use of "in-network" versus "out-of-network" residential building system service providers and access to more providers in a more expansive network. A comparable *Consumer-Driven Products* model may include a high-deductible residential building system plan paired with a tax-advantaged means for customers to pay for eligible residential building system expenses. These products would encourage customers to play an active role in managing their residential system and residential building system costs and operating like health savings accounts, reimbursement accounts, and flexible spending accounts. The government-funded Individual and Family Plans provider access would constitute a network of residential building system service providers in a geographic area selected based on cost and quality. A tailored model of Cigna's Integrated Medical commercial products for financial assets may also benefit financial asset manufacturers.

Levers for financial and intangible asset manufacturers

The manufacturers of financial assets may benefit from structuring their offerings analogous to Cigna's Group Disability and Other voluntary and specialty products, Integrated Medical commercial and specialty products and services such as stop-loss insurance, and International Markets' global health care models mentioned previously (refer to Table 28). Also, these companies may benefit from structuring their offerings like the range of Cigna's Group Disability and Other offerings.

The intangible asset manufacturers in Table 30 may benefit from the Health Services' clinical solutions model levers in Table 27. Innovative operational programs may help clients drive better residential building system outcomes at a lower cost. This model would identify and address potentially unsafe or wasteful building-related services, dispensing and using effective physical building solutions, and communicating with or supporting communications with building service and physical solutions providers. Cigna's Health Connect 360 SM offering presented a "transformational, outcomes-based clinical management program." A similar program in the residential building context may look like an outcomes-based operational program connecting effective, physical building solutions, living conditions, and building and occupier engagement data to develop insights. Consequently, tailored residential building system interventions to meet specific client needs may be delivered for improved quality and other operational outcomes. Mimicry of Cigna's Express Scripts Digital Health Formulary offering may yield a list of available digital residential building system solutions bearing operational effectiveness, user-friendly experience, data security, and financial value on the market for clients. A program similar to Cigna's Advanced Utilization Management programs may be a helpful tool for decreasing client spend on physical building solutions leveraging prior authorization, quantity management, residential building system lower cost solutions, and preferred specialty management. An investigative service program that would help plan owners identify potential problem occupiers and service providers with unusual or excessive utilization patterns similar to Cigna's Enhanced Fraud, Waste & Abuse program may plausibly surface.

Table 23: Cigna service manufacturing model levers

Cigna Create Value	Cigna Identify Value	Cigna Capture Value
Health Services - Home delivery and specialty services	1) No new customers or new benefits for customers	model-based pricing model, instant, single payment
Group Disability and Other - Leave administrative solutions (group disability), voluntary services (other)	1) Increase functional value for clients	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; market-based pricing, continuous payment of installments; model-based pricing, time-based subscription
Health Services: Supply chain administration and management - Retail network pharmacy administration	1) No new customers or new benefits for customers	model-based pricing model, instant, single payment
Health Services - Supply chain administration and management - Benefits Design Consultation	1) Improve functional value for existing job group (clients)	model-based pricing, continuous payment of usage
Health Services - Health Benefit Management Services	1) The same job groups become payors who gain economic value 2) Occupants gain experiential value	market-based pricing, continuous payment of installments; model-based pricing, time-based subscription
Health Services - Pharmacy Dispensing - Drug Claim Adjudication	1) No new customers or new benefits for customers	cost-based pricing model, instant, single payment

Table 23 continued

Health Services - Supply chain administration and management - Administration of Group Purchasing Organization	1) Increase functional value – no clear capture	
Health Services - Supply chain administration and management - Drug Formulary Management	1) Increase functional value – no clear capture	
Integrated Medical (Government) - Medicare Stand-Alone Prescription: Drug Products	1) economic and experiential value for new demographic (i.e. government-funded clients)	model-based pricing model; delayed, single payment
Integrated Medical (Specialty Products & Services) - Consumer health engagement, cost-containment programs, behavioral health, pharmacy management, dental solutions, stop-loss	1) Dental solutions analogy – increase functional value for psychographic group (i.e. standalone or independent individuals) 2) Behavioral health analogy - increase functional value for existing job group plus provide functional value for occupants 3) Pharmacy management, consumer health engagement, cost-containment analogy - increase functional value for need group (i.e. customers) 4) Stop-loss analogy – economic value for new psychographic group (i.e. self-insured clients) 5) Commercial – increase functional value for existing job group plus provide functional value for occupants 6) Government– experiential and economic value for new demographic group (government-funded clients)	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription
International Markets - global health care, local health care, supplemental health, and life and accident insurance products and services, as well as customers' term and variable universal life insurance.	1) Provide functional value for new demographic (i.e. individuals) in new geographic locations 2) Provide functional value for need group (i.e. individuals) 3) Provide functional value for new psychographic (i.e. globally mobile individuals) 4) Increase functional value for existing job group	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription

Table 24: Residential real estate cases service manufacturing model levers

Service Manufacturing Model	
Create Value	**Capture Value**
AvalonBay – property management	fee-for-service - value-based pricing, time-based subscription
AECOM - Management Services	value-based pricing, delayed single payment; cost-based pricing, continuous payment based on usage; cost-based pricing, delayed single payment; cost-based pricing, volume-based subscription
CherryHill - Construct and manage a portfolio of servicing related assets and RMBS (e.g. Aurora-licensed mortgage servicing subsidiary)	interest income - model-based pricing, usage-based continuous payment; securities for sale - market-based pricing, instant, single payment
DRHorton – Title agency services, planning and management activities related to entitlement, acquisition, community development, and sale of residential lots (Forestar)	Title agency services - model-based pricing, instant, single payments Sell of land and lots - market-based pricing, instant, single payments
JLL - Advisory, Consulting, and Other - workplace, digital solutions, valuations, consulting, and advisory leading professional services firm - Energy and Sustainability Services	shared savings or fee for service which are likely also value based. In this business segment, most of services are delivered over time following a usage-based, continuous payment structure. Other arrangements may be event-driven point-in-time transactions, which may characterize as delayed, single payment structures.
JLL - Capital Markets - equity placement, corporate finance services, loan servicing	retainer fee - value-based pricing, instant, single payment; commercial loan servicing fees - value-based pricing, continuous payment based on usage and instant single payments
JLL - Leasing - tenant representation	value-based pricing, delayed, single payment
JLL - LaSalle - acquisition, financing, leasing, management, and divestiture of real estate investments	value-based pricing, delayed, single payment;

Table 24 continued

JLL - Property & Facility Management - full-service IFM and property management	management fee - model-based pricing, time-based subscription; management fee - value-based pricing, time-based subscription; management fee - cost-based pricing, time-based subscription; cost reimbursement -cost-based pricing, time-based subscription; incentive fees - value-based pricing
Vornado - Building maintenance services (i.e. cleaning, security and engineering services)	fee - cost-based pricing, instant single payments
Welltower - Outpatient Medical - property management services	value-based pricing (market-based for Medicaid), time-based subscription
Welltower - Seniors Housing Operating - Asset and property management, leasing, marketing and other services	fee-for-service - value-based pricing, time-based subscription; rent and payment plans - value-based pricing, time-based subscription; entrance fees - instant, single payment
Zillow - Zillow Closing Services of title and escrow closing services, and advertising services	value-based pricing, instant, single payment

Table 25: Cigna service aggregation model levers

Service Aggregation Model					
Cigna Create Value	Health Services - Pharmacy dispensing - home delivery pharmacy services	Health Services - Provider services	Health Services - Pharmacy dispensing - Specialty services	Integrated Medical (Commercial)	Integrated Medical (Government) Individual and Family Plans provider access.
Cigna Identify Value	1) No new customers or new benefits for customers	1) Increased functional and economic value for current job group 2) Increased functional value for need group	1) No new customers or new benefits for customers	1) Increase functional value for existing job group plus provide functional value for occupants	1) Economic and experiential value for new demographic (i.e. government-funded clients)
Cigna Capture Value	model-based pricing model, instant, single payment		model-based pricing model, instant, single payment	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription

Table 26: Residential real estate cases service aggregation model levers

Service Aggregation Model	
Create Value	**Capture Value**
JLL - Property & Facility Management - full-service IFM and property management	management fee - model-based pricing, time-based subscription; management fee - value-based pricing, time-based subscription; management fee - cost-based pricing, time-based subscription; cost reimbursement -cost-based pricing, time-based subscription; incentive fees - value-based pricing
Welltower - Senior Housing Operating - senior apartments, independent living and independent supportive facilities, continuing care retirement communities, assisted living, Alzheimer's/dementia care homes with or without nursing	fee-for-service - value-based pricing, time-based subscription; rent and payment plans - value-based pricing, time-based subscription; entrance fees - instant, single payment
Welltower - Triple-net properties offer services including independent living and independent supportive living (Canada), assisted living, continuing care retirement communities, Alzheimer's/dementia care and care homes with or without nursing (U.K.) described above, as well as long-term/post-acute care.	Medicare reimbursement for leasing and long-term facilities - market-based pricing and time-based subscription; Medicare reimbursement for long-term facilities physician fee schedule - market-based and instant, single payment; rent - value-based pricing; time-based subscription

Table 27: Cigna's Service adder model levers vs. Physical asset distributor model levers vs. Intangible asset manufacturer levers

	Service Adder Model	**Physical Asset Distributor Model**	**Intangible Asset Manufacturer**
Create Value	Integrated Medical (Government) - Medicare Stand-Alone Prescription Drug Products: value-added services	Health Services - Provider Services	Health Services - Clinical Solutions
Identify Value	1) Economic and experiential value for new demographic (i.e. government-funded clients)	1) Increased functional and economic value for current job group 2) Increased functional value for need group	1) Economic value for current job group
Capture Value	model-based pricing model; delayed, single payment		model-based pricing, continuous payment of usage; model-based pricing, time-based subscription

Table 28: Financial asset manufacturer levers

Cigna		
Create Value	**Identify Value**	**Capture Value**
Group Disability and Other - commercial long- and short-term disability insurance products and term life group insurance products group personal accident insurance voluntary and specialty products	1) Increased functional and economic value for current job group	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; market-based pricing, continuous payment of installments; model-based pricing, time-based subscription
Group Disability and Other - run-off settlement annuity and businesses (other) (i.e. individual life insurance and annuity and retirement benefits businesses, reinsurance, settlement annuity)	1) Increase functional value for clients	model-based pricing, time-based subscription
Group Disability and Other - personal accident insurance (other)		model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; market-based pricing, continuous payment of installments; model-based pricing, time-based subscription
Group Disability and Other - corporate-owned life insurance (other) (i.e. permanent insurance)		model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; market-based pricing, continuous payment of installments; model-based pricing, time-based subscription

Table 28 continued

Integrated Medical - Managed care plans, PPO plans, consumer-driven products (i.e. high-deductable savings accounts, health reimbursement accounts, and flexible spending accounts) are paired with high-deductible medical plan, stop-loss insurance	1) Increased functional value for current job group	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription
Integrated Medical (Government) - Medicare Advantage plans, primarily HMO plans, Medicare Supplement Plans, Indvidual and Family Plans, Medicare Part D plans, Medicaid plans, and individual health insurance coverage on and off the public exchanges.	1) Experiential and economic value for new demographic group (government-funded clients)	model-based pricing model; delayed, single payment

Table 28 continued

Integrated Medical (Specialty Products & Services) - Dental solutions, Stop-Loss solutions	1) Dental solutions analogy – increase functional value for psychographic group (i.e. standalone or independent individuals) 2) Behavioral health analogy - increase functional value for existing job group plus provide functional value for occupants 3) Pharmacy management, consumer health engagement, cost-containment analogy - increase functional value for need group (i.e. customers) 4) Stop-loss analogy – economic value for new psychographic group (i.e. self-insured clients) 5) Commercial – increase functional value for existing job group plus provide functional value for occupants 6) Government– experiential and economic value for new demographic group (government-funded clients)	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription
International Markets - Global, local, supplementary health, life and accident health care products and services	1) Provide functional value for new demographic (i.e. individuals) in new geographic locations 2) Provide functional value for need group (i.e. individuals) 3) Provide functional value for new psychographic (i.e. globally mobile individuals) 4) Increase functional value for existing job group	model-based pricing, continuous payment of installments; model-based pricing, continuous payment of usage; model-based pricing, time-based subscription
Residential Real Estate Case		
DRHorton -DHI Mortgage - title insurance		fee - model-based pricing, instant, single payment

Table 29: Service adder model levers vs. Physical asset distributor model levers

	Service Adder Model	Physical Asset Distributor Model		
Create Value	**JLL** - Capital Markets - consultative advisory service - investment sales and acquisitions, debt placement, equity placement, and financing arrangement, investment sales and acquisitions	**AvalonBay** - Acquisition and disposition of communities	**DRHorton-** Acquisition and disposition of communities	**Zillow** - Zillow Offers home-buying program
Capture value	retainer fee - value-based pricing, instant, single payment; commercial loan servicing fees - value-based pricing, continuous payment based on usage and instant single payments	model-based pricing, instant, single payment	revenue - model-based pricing, instant, single payment	value-based pricing, instant, single payment

Table 30: Intangible asset manufacturer model levers

Intangible Asset Manufacturer Model							
Create Value	**AECOM** - Management Services	**Realogy** - RFG - Support franchisees with technology platforms	**Zillow** - IMT - Rentals - suite of tools, pay per lease product	**Zillow** - Property management services (e.g. listings, advertising and leasing, living database of residential homes)	**Zillow** - IMT - Others - display brand advertisements	**Zillow** - IMT - end-to-end real estate transaction management solution	**Zillow** - Mortgages - Mortgage software solutions including a pricing engine and lead management platform
Capture value	value-based pricing, delayed single payment; cost-based pricing, continuous payment based on usage; cost-based pricing, delayed single payment; cost-based pricing, volume-based subscription	royalty fee - model-based pricing, continuous payment based on usage; marketing fee - model-based pricing, delayed single payment; domestic franchise fee - model-based pricing, instant, single payment; area development fee -model-based pricing, continuous payment based on installment	advertising payment - model-based pricing, delayed, single payment application fee - model-based pricing, instant, single payment pay-per-lease advertising - model-based pricing, instant, single payment		model-based pricing, delayed, single payment	Premier Agent prepaid spend - model-based pricing, usage-based continuous payment; Dotloop - value-based pricing, instant, single payment	model-based pricing, instant, single payment; market-based pricing, instant, single payment (mortgages sold at fair value)

Table 31: Outcome manufacturing model levers

	Cigna			Residential Real Estate Cases		
Create Value	Pharmacy revenue - Single performance obligation to process claims, dispense prescription drugs and provide other services. Financial and performance guarantees (i.e. a minimum level of discounts a client may receive, generic utilization rates and various service levels)	ASO arrangements fees - Clinical solutions and health benefit management services have combined performance obligation - Clinical outcome or financial guarantees	Integrated pharmacy fees- Health benefit management solutions has a single performance obligation	**AECOM -** Management Services	**JLL** - Project & Development Services - design and management of real estate projects including fill-out services	**JLL** - Property & Facility Management - financial and operational results, and end-user experience

Table 31 continued

Capture Value	cost-based pricing model, instant, single payment; model-based pricing model, instant, single payment	model-based pricing, continuous payment of usage	model-based pricing, continuous payment of usage	value-based pricing, delayed single payment; cost-based pricing, continuous payment based on usage; cost-based pricing, delayed single payment; cost-based pricing, volume-based subscription	fee-for-service cost-reimbursement - cost-based pricing, continuous payment based on usage; fee-for-service - value-based pricing, continuous payment based on usage	management fee - model-based pricing, time-based subscription; management fee - value-based pricing, time-based subscription; management fee - cost-based pricing, time-based subscription; cost reimbursement -cost-based pricing, time-based subscription; incentive fees - value-based pricing

Table 32: Residential real estate manufacture physical assets case levers

Create Value	Capture Value
AECOM AECOM Construction Services: - Construction of large scale building and facility construction projects AECOM Management Services: Planning, design and construction of aircraft hangars, barracks, military hospitals and other government buildings	
AvalonBay Communities - Multi-use developments including infrastructure	The sale of condominiums follows a single payment structure where value is captured instantly at the time of sale. The real estate pricing is model-based.
DRHorton Single-family detached homes, attached homes (e.g. townhomes, duplexes, and triplexes) Ranch land Land for development DHI Communities - multi-family rental properties	DRHorton revenue is largely from homebuilding. Revenue from the sale of completed homes, land, and lots are instant, single payments dependent on market-based pricing recognized at the time of closing of a sale.
Howard Hughes Condominium rights and unit sales Operating Assets - property redevelopment from partial to full demolition of existing structures for new construction Strategic Developments	Revenue from the sale of individual condominium unit is recognized at closing, indicative of a value-based pricing, instant single payment structure.
JLL - The Project & Development Services	Negotiated fees with a possible cost reimbursement component - value-priced, usage-based continuous payment model. The cost reimbursement model indicates a cost-priced, continuous payment based on usage.
Vornado - Develop commercial and residential properties	It is assumed that asset sales, including condominium sales are priced based on value and received as an instant, single payment at the time of sale.

Feasibility of Analogous Cigna Business Levers

The viability of each analogous business model was assessed by sensing its practical implications in terms of the wheel of business model reinvention of Voelpel et al. (2004):

1. the potential improved customer benefits if each residential real estate company were to shift to the respective new lever
2. the potential power and paths from recent technological gains
3. the economic feasibility to implement Cigna's model levers
4. the possible business system infrastructure reconfigurations

Herein, the potential improved customer benefits if each company were to shift to the respective new lever. Like Cigna, AvalonBay manufactured services and distributed physical assets. Developers, re-developers, and building owners (job-based groups) received a functional benefit from Avalon Bay's services design. Firstly, service manufacturing business models like Cigna's Group Disability and Other leave administration solutions, Health Services' supply chain administration, and management retail network pharmacy administration models may increase functional value for existing job groups of developers, re-developers, and building owners (e.g., AvalonBay's property management clients). In the Health Services' health benefit management services analogous model, the same job groups become payors and gain economic value as occupants gain experiential value. The Integrated Medical comparable model for commercial clients may increase functional value for the existing job groups plus provide functional value for occupants. The Integrated Medical Medicare Stand-Alone Prescription Drug Products and overall government model analogous business model may yield economic and experiential value for a new demographic of government-funded clients. The Integrated Medical specialty products and services business model analogy for behavioral health solutions may increase functional value for existing clients plus provide functional value for occupants compounded with the potential new customer value for commercial and government model analogies. The pharmacy management, consumer health engagement, cost-containment analogous business models may provide functional value for a need-based group of customers. Also, the pharmacy management model may provide functional value for need-based client customer segments. The stop-loss analogy may provide economic value for a new psychographic group (i.e., self-insured clients). Secondly, building owners and re-developers, also job groups, received a functional benefit from AvalonBay's disposition of properties. The Health Services provider services business model may increase the functional value for these job groups and potentially provide economic value. The model may make an opportunity to deliver this functional value to need groups.

AECOM manufactured services and intangible assets. AECOM MS manufactured services such as operating and maintaining complex government (e.g., DOE and NDA programs) installations, including military bases and test ranges. AECOM MS new customer benefits for new service manufacturing business models are like those presented for AvalonBay. However, the job group currently provides functional value changes to global governments, businesses, and organizations, particularly the U.S. and U.K. Separately, AECOM MS manufactured intangible assets such as IT infrastructure design and implementation. The Health Services clinical solutions analogical business model may deliver economic value for current job groups (e.g., governments, businesses, and organizations).

Cherry Hill offered functional value to job-based segments (e.g., Freedom Mortgage and (assuming) other mortgage lenders and repurchase agreements counterparties) by building and managing a portfolio of servicing-related assets and RMBS using a licensed mortgage servicing subsidiary ("Aurora"). The potential customer gains for novice service manufacturing business models are like those presented for AvalonBay.

DRHorton manufactured services and financial assets and distributed physical assets. Firstly, DRHorton's Forestar acts as a manufacturer of services for physical assets by providing - planning and management activities related to the entitlement, acquisition, community development, and sale of residential lots. DRHorton's new customer benefits for service manufacturing new business models are like those presented for AvalonBay. However, the job group to which they currently provide functional value changes to homebuilders. Functional value is also captured from homebuying demographics which may also be improved under new models. Secondly, Forestar acts as a distributor of physical assets such as land and residential lots. In these cases, the sale of residential land and lots, typically single-family lots, provides functional value to homebuilders. Occasionally, commercially zoned parcels may be sold to commercial developers. The Health Services' provider services analogous model may increase the functional value for homebuilders and commercial developers. This new model may enable the delivery and monetization of economic value for current home builders and commercial developers and expand into opportunities to deliver functional value for need groups. Thirdly, DHI Mortgage manufactured financial assets (e.g., title agency services) to support its title insurance offering. The functional value of servicing rights and mortgage loans is sold to the job group of third-party mortgage loan purchasers. The opportunity to monetize an increase in functional value provided to third-party mortgage loan purchasers is available from the Group Disability and Other, Integrated Medical (overall and commercial) business model analogies. Additionally, the Integrated Medical Government business model analogy may potentially capture value from economic and experiential offerings for new demographic groups (government-funded clients). Furthermore, functional value may be offered to parties connected to clients with the Integrated Medical commercial analogy.

The following opportunities exist from the:

1) Integrated Medical Specialty Products & Services business model analogies:
    a. deliver functional value for a psychographic group (e.g., standalone or independent individuals) using the dental solutions analogy
    b. offer functional value for need-based groups of potential clients and customers using the pharmacy management analogy
    c. forge functional value for a need group (i.e., customers) from consumer health engagement, cost-containment analogies
    d. cast economic value for a new psychographic group (i.e., self-insured clients) with the stop-loss analogy
    e. behavioral health analogy may increase functional value for existing job groups plus provide functional value for occupants
2) The International Markets analogous business models could provide
    a. provide functional value for new demographic (i.e. individuals) in new geographic locations
    b. provide functional value for a need group (i.e., individuals)
    c. provide functional value for a new psychographic group (i.e., globally mobile individuals)

    increase functional value for existing job group

JLL’s manufacturing and aggregation of services may benefit from analogous Cigna business models. Specifically, the energy and sustainability professional services in the Advisory, Consulting, and Other segment, the Capital Markets, Leasing, LaSalle, and Property & Facility Management segments manufacture services. The Advisory, Consulting, and Other segment's energy and professional sustainability services offer 1) economic value to need groups of public and private sector commercial real estate property owners, investors, and financing sources 2) experiential value to the need group of occupiers. New job-based customers may be gained from the Group Disability and Other leave administration solutions, Health Services supply chain administration and management retail network pharmacy administration, and the Health Services health benefit management services analogous service manufacturing business models - albeit some may exist in the current clientele. Under the Health Services health benefit management services analogous business models, the potential to improve and capture occupants’ experiential value exists. Supply chain administration and management group purchasing organization administration and drug formulary management analogous business models could result in new functional value for existing or new job-based clients. Still, there were no apparent means to capture this value. The opportunity to provide and monetize functional value to the current occupant clientele may exist from the Integrated Medical behavioral health, pharmacy management, consumer health engagement, cost-containment analogous business models. Additionally, the pharmacy management model may provide functional value for need-based clients. The new customer values created from Integrated Medical analogous models remain the same as those for AvalonBay.

The Capital Markets segment provides functional and economic value for job groups (lenders). New customer benefits for service manufacturing new business models are like those presented for AvalonBay. However, the job group to which they currently provide functional value changes to lenders. Lenders may benefit from an increased functional value from the Group Disability and Other leave administration solutions, Health Services supply chain administration, and management retail network pharmacy administration analogous business models. An additional opportunity to propose and capture economic value from lenders may exist under these new models and the Health Services health benefit management services analogous business model. Under the latter business model, opportunities to propose and monetize experiential value for customers connected to lenders may exist. Supply chain administration and management group purchasing organization administration and drug formulary management analogous business models could increase functional value for existing clients. Still, there were no apparent means to capture this value. The Integrated Medical analogous model for commercial clients may increase functional value for lenders plus provide functional value for customers connected to clients. The Integrated Medical Medicare Stand-Alone Prescription Drug Products and overall government model analogous business model may yield additional economic and new experiential value for a new demographic of government-funded clients. The Integrated Medical Specialty Products & Services business model analogies to provide dental solutions may increase functional value for a new psychographic group (i.e., standalone or independent individuals) in addition to the potential new customer value for commercial and government model analogies. Behavioral health solutions may increase functional value for existing clients plus provide functional value for customers connected to clients. The pharmacy management, consumer health engagement, cost-containment analogous business models may give functional value for a need-based group of customers. The pharmacy management model may provide functional value for need-based client segments. The stop-loss analogy may provide economic value for a new psychographic group (e.g., self-insured clients).

The Leasing and LaSalle segments offered functional value to property owners' need-based clients (i.e., investors, developers, property companies, and public entities) and mature investors, respectively, albeit job-based groups may exist within each segmentation. The Group Disability and Other leave administration solutions, Health Services supply chain administration, and management retail network pharmacy administration analogous business models for manufacturing services may result in functional value for new job-based customers. The economic value may also be gained from these potential customers under the Health Services Health benefit management services analogous business model, as the experiential value may be delivered to clients of customers. The Integrated Medical pharmacy management, consumer health engagement, cost-containment analogous business models may increase functional value for this need-based clientele. The pharmacy management model may provide functional value for existing need-based clients. The new customer values created from Integrated Medical analogous models remain the same as those for AvalonBay.

The Property & Facility Management segment provides 1) economic and functional value to corporations and institutions (job groups) and 2) experiential value to tenants of clients (need group). New customer benefits for service manufacturing new business models are like those presented for AvalonBay. However, the job group to which they currently provide functional value changes to corporations and institutions. The opportunity to monetize potential increase in functional value for corporations and institutions exists for the Group Disability and Other leave administration solutions analogous business model, Health Services supply chain administration and management retail network pharmacy administration analogous business model, the Health Services Health benefit management services analogous business model, supply chain administration and management group purchasing organization administration and drug formulary management analogous business model, the Integrated Medical analogous model for commercial clients, and the Integrated Medical behavioral health solutions analogous model. The Health Services health benefit management services model may enhance economic value corporations and institutions as occupants gain improved experiential value. The Integrated Medical analogous model for commercial clients may boost functional value for occupants. The Integrated Medical pharmacy management, consumer health engagement, cost-containment analogous business models may provide functional value for client's tenants. The other potential customer gains from analogous Integrated Medical models remain the same as AvalonBay.

As service aggregators, Property & Facility Management segment may generate new customer value from the Health Services provider services, and Integrated Medical business model analogies. The Health Services provider services business model analogy may advance the current functional value and produce new economic value for corporations and institutions while originating functional value for clients' tenants. The Integrated Medical Commercial business model analogy may also increase functional value for corporations, institutions, and tenants. The Integrated Medical Government business model analogy may cultivate economic and experiential value for new demographics (i.e., government-funded clients).

Realogy's segment "RFG" manufactured intangible assets offering real estate brokerage franchises. RFG offered functional value to franchisees and independent sales agents (job-based group) and the functional value of needing to sell or purchase a home to franchisees' customers (need-based group). Health Services clinical solutions analogical business model may provide economic value for franchisees and independent sales agents.

Vornado manufactured building maintenance services. Building maintenance services offers functional value and experiential value 1) to commercial tenants and their customers (job-based customers) and 2) homebuyers and renters (need-based customers). The Group Disability and Other leave administration solutions, Health Services supply chain administration, and management retail network pharmacy administration analogous business models for manufacturing services may increase functional value for commercial tenants and customers. In the Health Services health benefit management services analogous business model, the commercial tenants become payors and gain economic value as customers who connect with these tenants gain experiential value. The Integrated Medical analogous pharmacy management, consumer health engagement, cost-containment analogous business models may provide functional value for home buyers and renters. The Integrated Medical analogous behavioral health solutions may increase functional value for existing commercial tenants plus provide functional value for customers connected to clients. The Integrated Medical analogous model for commercial clients may increase functional value for their current customer base. All other customer benefits for Integrated Medical analogous models discussed in AvalonBay are valid here.

Welltower manufactured and aggregated services as well. In the Outpatient Medical segment, property management services were manufactured. The Outpatient Medical business enables functional value for local health care providers (job-based) and patients (need-based group). In the Seniors Housing Operating segment, asset and property management, leasing, marketing, and other services were manufactured. The Senior Housing Operating provides functional value to the 55+ years old demographic; job-based segments of private pay sources and Medicaid and Medicare regulators, and housing operators; and experiential value to demographic populations (e.g., senior Canadian residents) and psychographic groups (e.g., seniors in need of assistance with daily living activities, and patients seeking post-acute care). The Group Disability and Other leave administration solutions, Health Services supply chain administration and management retail network pharmacy administration analogous business models for manufacturing services may increase functional value for health care providers in the Outpatient Medical business and private pay sources in the Senior Housing Operating segment. Under the Integrated Medical analogous model for commercial clients, functional value for the existing job groups may increase, and some may be created for their customers. In the Health Services health benefit management services analogous business model, the same job groups become payors, if they are not already, and gain economic value and pass along as experiential value parties connected to clients them. The Integrated Medical Medicare Stand-Alone Prescription Drug

Products and overall government model analogous business model may yield new economic and enhance the experiential value for the 55+ years old demographic of the Senior Housing Operating segment. The Integrated Medical Specialty Products & Services business model analogies for behavioral health solutions may increase functional value for existing job-based groups and provide extra functional value for existing customers plus the potential new customer value for commercial and government model analogies. The stop-loss analogy may provide economic value for the current psychographic groups. The pharmacy management, consumer health engagement, cost-containment analogous business models may give functional value for unreached need-based customers (and clients in the pharmacy management model).

Welltower's services were aggregated in the Senior Housing Operating and Triple-net properties segments. Triple-net properties generate functional value for job-based customers like the U.S. federal and state governments (i.e., Medicaid and Medicare regulators), physicians, hospital outpatient departments, and ambulatory surgical centers. The Senior Housing Operating and Triple-net properties segments provided experiential value to demographic populations (e.g., senior Canadian residents) and psychographic groups (e.g., seniors needing assistance with daily living activities and patients seeking post-acute care). Other Senior Housing Operating segment's identified value was discussed previously. The current Triple-net properties and Senior Housing Operating beneficiaries - U.S. federal and state government payors (i.e., Medicaid and Medicare regulators), physicians, hospital outpatient departments, ambulatory surgical centers, private pay sources, and housing operators - may benefit from additional functional value gained from the Integrated Medical Commercial business model analogy. This value may be transferable to other relevant parties. The functional value may also increase with the Health Services provider services business model analogy for these job groups. Complementary, this business model may yield additional economic for those job groups and provide functional value for new need-based customer segments. The 55+ years old demographic may benefit from new economic and increased experiential value ushered in by the Integrated Medical (Government) business model analogy complementary to the current functional value offerings.

Zillow manufactured services and intangible assets and distributed physical assets. Firstly, Zillow Closing Services in Homes manufactured title and escrow closing services. It is assumed that these services are for the need-based customer segment of homebuyers. These services provide functional value to homebuyers, emotional value during a stressful period, economic and experiential value to borrowers and home sellers. The Integrated Medical pharmacy management, consumer health engagement, cost-containment analogous business models may provide functional value for this need-based group of customers. The customer benefit gains for analogous business models to manufacture services in the AvalonBay section are relevant here. Secondly, Zillow manufacturers intangible assets across different segments for different job-based customers segments. Their intangible asset offerings include property management services - listings, advertising and leasing, living database of residential homes, complementary rentals marketplace, and rental transaction services platform - pay per lease product and a suite of tools (e.g., rental application platform) in the IMT Rentals segment, brand advertisement display in the IMT Others segment, end-to-end real estate transaction management solution generally in the IMT segment, and mortgage software solutions including a pricing engine and lead management platform in the Mortgages segment. Lastly, the home-buying program in Zillow Homes may acts as a distributor of physical assets if no work has been completed on the purchased home. It can be assumed that the Health Services Provider Services business model may offer new functional and economic value for new job-based customer groups. The current need-based customer segments of homebuyers may receive additional functional value with this new business model. Suppose the Homes segment provides functional, social, and experiential value to real estate agents (job-based customer segment). In that case, the opportunity to monetize from increase functional value and new economic value may exist in this new business model. Overall, Zillow offers functional, social, and experiential value to real estate agents. The Mortgages segment gives functional value to mortgage lenders and other mortgage professionals, secondary mortgage market. The Others segment contributes functional value to job-based groups, businesses, and professionals associated with residential real estate and rental industries (i.e., real estate and rental professionals and brand advertisers, brokerages, real estate agents, REALTORS members). Similarly, the Rentals segment within IMT supplies rental professionals, landlords, property managers, and other market participants. Also, the Others segment within IMT supports home builders and advertisers. The Health Services Clinical Solutions analogous business model provides economic value for these job groups.

The business models with clear mechanisms to capture value and identify value were evaluated. For example, Company A’s potential analogous business models to Cigna’s supply chain administration and management, group purchasing organization administration, and drug formulary management could increase functional value for existing clients. Still, there were no straightforward means to capture this value. Separately, Cigna's identified value for Pharmacy Dispensing services is unclear; therefore, the potential customer value gains were not discussed.

Cigna's technology and data analytics deliver new customer value, protect value creation, and offer a competitive advantage. The new value created from the new analogous business models is discussed in this section. The mainspring of the Company's strategic innovation is Cigna Technology Services, their "*business-aligned technology project portfolio in insights and analytics, digital health and care delivery and management*" (Cigna Corporation, 2020). The new customer value created from Cigna's technology strategy is enhanced customer experience, increased health system engagement, population health advancements, and the ability to predict customer needs and meet them where they are. For example, technology enables retail pharmacies to focus on patient care. Hundreds of thousands of medication errors are avoided annually due to real-time safety checks, predicted and prevented chronic diseases, reduced payments, and reduced claims fraud (Cigna Corporation, 2020). Their pharmacy technology platform enables safe, quick, and accurate adjudication of over one billion adjusted prescriptions annually (Cigna Corporation, 2020). The whole person's health is optimized by leveraging data from wearable devices and the Internet of Things.

Data and analytics generate new value for customers and stakeholders by enabling better insights and actionable intelligence for the design of more affordable benefit plans and services; the development of new, digitally enabled solutions and innovative data and analytics driven services for customers and clients to improve care costs and health outcomes (Cigna Corporation, 2020). Evidence-based medical and pharmacy benefits management evaluates clinical, economic, and individual impacts of benefit designs, programs, and improvements. This innovation promotes new customer value through "*new and more effective ways to close care gaps, optimize treatment and improve outcomes*."

There are several benefits of adopting the technology and analytics strategy from Cigna into the business model analogy. Potential technological solutions could 1) provide enhanced and appropriate customer experience, 2) forecast client and customer needs, 3) progress residential building performance household, 4) allow service providers to focus on timely residential building system support with reduced technological errors, 5) predict, prevent or protect against damaging or debilitating residential living conditions 6) reduced costs 7) real-time data can be enabled from whole-building performance. Adoption of the data and analytics strategy could generate 1) better housing outputs 2) digitally enabled and data-driven solutions that reduce residential building system costs and outcomes for clients and occupants 3) allow for impact evaluation of designs, programs, and improvements 4) innovative and more effective ways to optimize usage, solutions and improve outcomes residential building performance gaps. These technological benefits translate to customer-oriented metrics of whole building performance.

The economic feasibility of Cigna's profit model is dependent on the success of each lever in each business segment. Revenue growth was exhibited in the Health Services' pharmacy dispensing, supply chain administration and management, clinical solutions, and value-based programs, primarily due to the addition of Express Scripts and the Integrated Medical segment, and cash flows from operating activities increased proving the financial success of this businesss model (Cigna Corporation, 2020). Operating cash flows consisted of pharmacy revenues and costs – such as network revenues, home delivery, and specialty revenues - premiums, fees, investment income, taxes, medical costs and other benefit expenses, SG&A, amortization of acquired intangible assets, interest expenses, and realized investment gains (losses) principally. Table 33 presents the influential factors on business model profitability. Cigna technology and analytics were supported by several fixed and variable costs. The fixed costs include claims processing facilities, point-of-sale retail pharmacy claims processing electronics, pharmacy technology platform development, and analytic and big data technologies. The variable costs had 7,000 in-house employees and significant external resources who provide information systems support (e.g., health benefit claims processing, and specialty and home delivery pharmacy systems), data and analytics talent, and talent development. Outsourced client and customer information security was another cost.

Table 33: Key factors that influence the profitability of each segment

Segment	Factors that impact profitability	Business model analogy
Health Services	Clients' claim volumes, mix, and price (e.g., generic fill rate)	Technological or physical building asset volume, mix, and price
	Client contract pricing for supply chain contracts for pharmacy network pharmaceutical and wholesaler purchasing and manufacturer rebates	Building technology and assets contract pricing for technological or physical asset purchasing and manufacturer rebates
	Inflation rate for prescription drugs	Relevant varying financial factors
Integrated Medical	Customer growth	
	Revenues from integrated specialty products, including pharmacy services sold to clients and customers across all funding solutions	Revenue from integrated specialty products
	Percentage of Medicare Advantage customers in plans eligible for quality bonus payments	Percentage of government-funded customers in higher-earning plans
	Benefit expenses as a percentage of premiums (medical care ratio or "MCR") for insured commercial and government businesses	Residential output expenses as a percentage of premiums (sustainable solution care ratio) for insured commercial and government businesses
	Selling, general and administrative expense as a percentage of adjusted revenues (expense ratio)	
	Unpaid claims and claim expenses	
International Markets	Premium growth, including new business and customer retention;	
	Benefit expenses as a percentage of premiums (loss ratio)	Residential output expenses as a percentage of premiums (loss ratio)
	Selling, general and administrative expense and acquisition expense as a percentage of revenues (expense ratio and acquisition cost ratio)	
	The impact of foreign currency movements	Relevant varying financial factors
Group Disability and Other	Premium growth, including new business and customer retention	
	Net investment income	
	Benefit expenses as a percentage of premiums (loss ratio)	Residential output expenses as a percentage of premiums (loss ratio)
	Selling, general and administrative expense as a percentage of revenues excluding net investment income (expense ratio)	

New business roles gained from new analogical levers were determined from how Cigna protects value. Partnerships across the residential real estate development supply chain, overall residential real estate industry, as well as the markets for complementary goods (e.g., furniture, equipment) and residential services (e.g., utilities, financing) could be organizational resources to protect the new value creation from residential buildings under new business models.

New business models may require a change in network roles and effectiveness for the real estate industry to improve building effectiveness. First, physical asset value creation protection may shift. New partnerships and third-party contracts with sustainable manufacturers, servicers, and other primary owner/occupant cost sources may be required for broad access to products, cost-containment programs, and residential product/service networks management. In the cases of value creation from services, non-exclusive contracts, and custom programs with (sustainable) residential product manufacturers, and sourcing residential services at wholesale prices may protect the new value creation. In the case of physical asset distribution, becoming a contracted service provider for major group purchasing organizations may be beneficial to protect the new value. Secondly, safeguards for intangible asset value creation may change. Patents, strategic technological innovation, and research and analysis to 1) optimize building performance interventions, 2) design affordable benefit plans services that serve direct stakeholders, reduce building-related costs, and improve living outcomes protect new value creation. Third-party partnerships to protect sensitive client and customer information and manage benefit processing information systems may also be necessary. Third, fortification for financial asset value creation may be utilized. New or modified contracts service with payors and critical relationships with clients, customers, service providers, product manufacturers, and payors may be new organizational practices to prevent disruption to value creation. Purchasing reinsurance from unaffiliated reinsurers and retention risk management may also be necessary depending on the creation of financial asset value. Last, talent contracts and strategic alliances with service providers, data and analytics expertise, a team to generate and update lists of the most effective local residential building-related products and financial analysts, and any specialty residential service expertise may be new mechanisms to protect value creation from human assets.

Feasibility of Analogous MassDOT I-91 Viaduct Rehabilitation Business Levers

The MassDOT business model analogy for manufacturing outcomes through physical assets translates to residential buildings replacing the Interstate 91 viaduct. Stakeholders in the study were the local business community, elected and local officials, community groups and organizations, individuals, property owners, planning commissions, industry organizations, transit agencies, and railroad and transit agencies located in and around Springfield, West Springfield, Chicopee, Agawam, Holyoke, and Longmeadow (Milone & MacBroom, Inc., & The Massachusetts Department of Transportation. 2018). The I-91 viaduct customers are identified as a demographic group within the primary and regional study area. The physical area for potential physical transportation system improvements is the primary study area.

The MassDOT business model endorsed capturing functional, economic, and experiential value to local demographic groups. The demographic segmentation distinguishes the different groups affected by the physical asset from a broad perspective. The real estate companies that manufacture physical assets may account for other stakeholder groups at the project level but likely miss how to deliver and capture functional, economic, and experiential value from unreached groups. DRHorton was the only company that segments its customers by demographic and delivers functional and economic value in this group of companies. DRHorton may expand their offerings to provide experiential value using this business model analogy. There may be an opportunity for AECOM, AvalonBay, Howard Hughes, JLL, Vornado to deliver and capture functional, economic, and experiential value from affected local demographic groups. The current customer benefits for each company are discussed in the consequent paragraph.

AECOM Construction and Management Services manufacture assets. AECOM provided functional value for specific job groups such as governments, businesses, and organizations globally. National government agencies in the U.S. often retain AECOM MS, and U.K. AvalonBay captures value from manufacturing and adding value to physical assets through asset sales, development, and redevelopment fees. AvalonBay provides functional value to infrastructure participants, likely similar to those accounted for in this project. However, the brief mention of this customer segment positioned it as a population that needs the infrastructure as part of the multi-use development. Homebuyers were another need-based segment that received functional benefits from the Company’s multifamily communities. Building owners and re-developers, also job groups, received a functional benefit from property sales. DRHorton creates value from manufacturing physical assets such as single-family detached homes, attached homes (e.g., townhomes, duplexes, and triplexes), ranch land, land for development, and owns and operates oil and gas-related assets. Their single-family detached homes and attached homes (e.g., townhomes, duplexes, and triplexes) offer the homebuyer demographic, functional value of buying a home, and economic value with offerings across different price points. Moreover, they deliver economic value by catering to different psychographic homebuyers such entry-level, first-time, first-time move-up, relocating in a short time frame, higher-end move-up, luxury, and those preferring an affordable and low-maintenance lifestyle; and homebuyers with specific needs such as speculative homebuyers. HHC manufactures and adds value to physical assets through property development and redevelopment of condominium and commercial developments. HHC offered an experiential value of places to work and shop for a specific psychographic group in cities (e.g., Seaport District). HHC offers functional value to need and job-based customer segments. Need-based segments include third-party companies seeking advertisement space, condominium buyers/homeowners, event attendees, and retail customers. Job-based groups included third-party companies seeking event space, residential homebuilders and developers, and non-competing land users (e.g., hospitals) who received the functional value of an event venue or land, respectively. JLL Project & Development Services segment provides functional value to need-based clients; leased space tenants, self-occupied building owners, and real estate investment owners from public entities and educational institutions primarily in the U.S. Vornado manufactured physical assets in the form of commercial and residential property development. Vornado mostly offered functional value and secondarily offered experiential value to customers connected by job group (i.e., commercial tenants and customers) and identified by need (i.e., home buyers and renters).

The "profitability" of the project costs could be estimated from the project revenue and costs. The property tax revenue for each project scenario was estimated. The project costs considered were the construction and maintenance costs. The funding for programming, design, and permitting costs were excluded. The order-of-magnitude/implementation cost was estimated from design take-offs, comparable project costs, and overall project contingencies to assess the feasibility of expected costs for each alternative. The right-of-way cost and the order-of-magnitude/implementation cost were the construction costs evaluated. The project maintenance costs were generated using the annual maintenance costs and overall life cycle costs. However, the feasibility of each project scenario was assessed by accounting for the costs alongside other impacts of mobility and accessibility, safety, environmental effects, land use and economic development, and community effects—the tax revenue aided in quantifying the economic development potential. Modern viaduct technologies and structural design features to support the rehabilitation were mentioned but the report focused on specific new customer values or efficiencies. The business system infrastructures for the real estate companies may not change significantly except for stakeholder partnership expansion.

7. SYNTHESIS OF FINDINGS AND IMPLICATIONS

A symbiotic, robust view of the building as a system characterized unexplained performance and inferred the potential for connective efficacy metrics to satisfy the needs of multiple stakeholders longitudinally. New levers may exist to generate new business models to capture this newly identified value. The qualitative and mixed-methods studies tested and confirmed Hypothesis 1, and the business model innovation study tested and confirmed Hypothesis 2.

7.1 Synthesis of the Design for Efficacy Study

Building design and development decisions produce building system attributes. The pairwise agent-to-agent interactions' resultant system-level performance is a nexus for the longitudinal benefits and costs of the building system and its ecosystem. Correspondingly, the quantitative results tested the three sub-hypotheses A-C and generalized the qualitative results (e.g., building value, outcomes, use contexts, and stakeholders); quantifying the environmental, economic, and cultural tangible and intangible impacts of buildings on stakeholders.

Recall the following hypotheses tested in the mixed-methods study:

A. Building performance depends on the social and technical variables of the building stakeholders and environment.
B. Buildings affect the economics, environmental, cultural, and health of people who use or are in proximity to them.
C. The value of buildings is dependent upon the needs and goals of the people (or stakeholders) who use them.

The quantitative analyses showed that the building value embodied social and technical variables of the direct stakeholder and the building ecosystem. For example, an individual's willingness to pay for a reduced crime rate is a social variable. Energy consumption is a technical variable. The context of use may be social, technical, or socio-technical, and building use externalities were an environmental variable. Also, economic, environmental, cultural, and health impacts such as expected returns, energy poverty, household greenhouse gas emissions, daily living conditions, and environmental health were estimated. Also, the building value from the stakeholder's perspective was in its enablement of their goals (e.g., living a healthy life or sustaining food security). The composition of the cost-benefit analyses generalized the qualitative results as the building value for specific stakeholders and associated building impacts are interchangeable.

Thus, as derived from its impacts, the purpose of a residential building is to yield net positive economic, environmental, health, and cultural outcomes for direct stakeholders as a result of their building-related consumption; for the building, the purpose is the reason interaction is sought. Therefore, building effectiveness may be measured in at least four dimensions in terms of its outcomes and values at the relevant stakeholder level (e.g., individual/household, organizational/group, or societal). The first dimension the building system design should improve is the stakeholder economic impact, such as enhanced quality of life and economic growth. Accordingly, negative outcomes like energy poverty, unmet energy needs, financial distress, food insecurity are minimized, and positive outcomes such as housing affordability, cost savings, housing outcomes, good living conditions are intentionally supported. The second dimension the building system design should improve is the environmental impact and sustainability. Consequently, positive stakeholder environmental outcomes should be enhanced as negative stakeholder environmental outcomes should be curtailed. For example, building energy conservation and savings are positive environmental outcomes for energy payors in the building system. Demand response outcomes are positive outcomes for energy providers. Sustainable development and environmental protection are positive societal outcomes, as greenhouse gas emissions are negative. Also, the effect of the building as an indoor environment creator may be measured through its effectual comfort conditions and daily living activities for the household/individual. Human health – physical, mental, and public – was the potential third dimension to measure building system performance. The building system should not damage and should potentially improve relevant stakeholder health status and outcomes. It should not induce health problems or increase health risks for stakeholders. The building system should support stakeholder cultural dimensions such as social sustainability and social responsibility. Social sustainability and social responsibility generally occur at the organizational level but can affect individuals/households and society.

Building performance modelling should account for this diverse set of variables and dimensions. The building attributes, outcomes, and values collectively constitute the performance of the building system, and one is not more important than the other. The understanding of all three performance elements comprised a more complete formulation of building performance. Building attributes would change as the context of building use changes.

7.2 Implications of the Design for Efficacy Study

The design for efficacy study may improve building design, research, and practices. The system-level classifications of building agents in section 5.1 provide the opportunity to connect building agents (often employed for functional purposes) and study the system-level outputs of multiple technologies on outcomes. The presented socio-technical framework of building performance provides a view to re-orient building performance by spatially and temporally connecting upstream decision-making with downstream stakeholder outcomes. The proposed framework is well-suited to reframe the building performance challenge for a few reasons. First, the model highlights macro-level and micro-level perspectives of techno-economic and socio-technical paradigm changes. The building has social, cultural, environmental, and economic implications that are difficult to quantify and evaluate against functional design objectives. This model should help overcome the barrier that traditional building design approaches have in concretely designing for the intangible impacts of buildings. Secondly, it facilitates systematic investigation, comparison, and solution generation across societal needs, impact categories, and contexts, allowing for crossing scales and contexts. Thirdly, the model focuses on the often-ignored opportunities to make early decisions that shape an innovation's future impact, connecting upfront beneficiaries to design implications and addressing the longitudinal stakeholder variability from the beginning. The introduction of outcomes to the existing efficiency paradigm does not negate it, but instead expands it to ensure that beneficiaries receive the best value for their resources. The introduction of outcome measurement to the building context allows an opportunity to prioritize, and evaluate, the impact of solutions to allocate stakeholder resources to maximize outcomes/value optimally.

Understanding social and technical variables and dimensions may help distinguish and examine which factors hinder or support desired building performance when predicted results are not realized. Inaccurate or overlooked assumptions causing suboptimal or varying building performance or inadvertent perpetuation of stakeholder barriers to achieving higher performance levels may be reduced as this longitudinal view of building performance may expose such gaps in the current building design and development process. Modern performance barriers such as the hesitation or unwillingness of beneficiaries to invest in or change habits for higher building performance may result from the output-oriented focus of the design. The longitudinal building system could be connected by considering or setting operation phase outcomes and values as design goals in the development stage instead of predicted operational outputs (e.g. energy consumption) or upstream stakeholder values (e.g., profit). Long-term beneficiaries of the building system may participate in activities that produce the desired outcomes. For the performance-based management of buildings, the design and development process must start with the identification of medium to long-term building effects ideally set to meet the needs and values of those with a high-level of engagement with the space, then shorter-range targets with quantifiable orders of a given variable for a specific duration can be established. Thereafter, budgets and performance indicators may be derived by decision-makers invested in the economic outputs. This process may align early and downstream economic and design decisions with outcomes. Target setting techniques should yield the appropriate translation of intended building outcomes to outputs, capture improvements for a single output or outcome (assuming a finite number of required inputs and activities), require ownership by key beneficiaries, be set for all relevant variables, and be accompanied by a performance indicator that offers a consistent measurement of temporal progress over time toward performance goals and impacts (Castro, 2011). This approach would allow beneficiaries to track longitudinal building performance through the causal results chain.

Overall, the optimal building value is dependent on the temporal alignment of the distribution of costs, benefits, and risks for beneficiaries. First, understanding the specific beneficiary effectiveness metrics is critical to optimizing the building value. Then, understanding which stakeholder is responsible for the risk of a specific benefit is important. The systems view of building performance, knowledge management scheme, cost-benefit analyses and innovative business models may persuade key stakeholders to create new partnerships or assess the impact of their building in a different way. The systems and longitudinal views of building performance, the knowledge management scheme, and cost-benefit analyses may create an emergent strategy to unfold performance and impact. It is recommended that an emergent strategy to test potential solutions should be in alignment with the ETF behaviors after communicating and defining paths for innovation opportunities.

The classification of building system agents, outcomes, and values support strategic innovation and the measurable impact for the residential project technical inputs and outputs in the 2020 LEED Residential Single Family Homes rating system (U.S. Green Building Council, 2021a), the LEED existing cities and communities rating system (U.S. Green Building Council, 2021b), and the LEED cities and communities plan and design rating system (U.S. Green Building Council, 2020c). The LEED existing cities and communities rating system covers many of the identified values; however, it is at the building ecosystem level. This rating system could be extended to include building-level outcomes and values for intentional building-level improvements to then flow into community-level improvement. Many of the outcomes and values in this research are addressed in the LEED Impact categories in Owens et al. (2013). As additional support of this effort, this work offers an integrated view of residential building performance, providing the platform to attain and measure building impacts.

7.3 Synthesis of the Business Model Innovation Study

The building ecosystem may be leveraged to deliver the newly identified value manufacture residential building system outcomes. The outcomes and values from the mixed-methods study may serve as an anchor for new business models. For example, the importance of development efficiency to the developer's profit was quantitatively observed in Scenario B2. The I-91 viaduct BM components showed a potential path for generating new revenue using multi-stakeholder efficacy metrics from manufacturing physical assets.

The harmonization of BM components to manufacture outcomes like Cigna was subsequently discussed. Cigna offered customers economical, functional, and experiential value segmented by needs, psychographics, jobs, and needs across each value proposition to manufacture outcomes. Contrarily, the residential real estate cases primarily segmented customers in one or two ways. For example, Cigna supplied economic value across different types of customers such as commercial and government payors (a job-based group), providers, government-funded individual/patients (a demographic group), specialty need individuals/patients (a need-based group), and self-insured clients (a psychographic group) as shown in Table 17. In contrast, to illustrate, AvalonBay offered economic value to apartment renters (a need-based group). Similarly, JLL offered economic value to CRE property owners and investors from the public and private sectors (all need-based groups) and lenders, institutional advisors, corporations, and institution clients (job-based groups). Therefore, a new characterization of customers, or new customers, may support new business models or opportunities. Additionally, Cigna provided economic, functional, and experiential value in its offerings as the residential real estate cases offered one or two of those value dimensions with AvalonBay, JLL, and Zillow as the exceptions as shown in Table 17. In the other residential real estate cases synergies may exist to expand the value received by the customer in existing offerings, toward the building value and outcome dimensions presented in Ch. 5.

Cigna was observed to manufacture outcomes by utilizing services, physical, intangible, and financial assets as shown in Table 18. AECOM was observed to manufactured outcomes by leveraging value creation from these asset types as well. Realogy and Zillow created value from these asset types, but the deliberate outcome-oriented business models were unclear. Consequently, Realogy and Zillow may be well-positioned to manufacture outcomes with the addition of a performance-based metric tied to the payment structures or pricing. Similarly, JLL manufactured outcomes from these asset types minus intangible assets. DRHorton, Vornado, and Welltower created value from these asset types minus intangible assets, but deliberate outcome-oriented business models were not clearly expressed. Therefore, value creation from intangible assets may prepare JLL, DRHorton, Vornado, and Welltower to manufacture outcomes. Except for AECOM, the other nine residential real estate cases may manufacture outcomes by creating new value from new asset types and linking all value creation to stakeholder-oriented performance measures.

Table 20 showed Cigna delivered value utilizing high and low direct and indirect engagement tactics, emphasizing indirect high engagement (e.g., through providers, pharmacies). The residential real estate cases generally used direct – high and low – engagement approaches. DRHorton, JLL, and Zillow employed three different tactics to deliver value to consumers; however, only one indirect – high or low – tactic would be used. Zillow, like Cigna, delivered value through non-affiliated facilities and through delivery metrics of accuracy, speed, security, and comfort and as likely well-positioned to manufacture outcomes. All other companies can improve their engagement touchpoints, as shown in Table 20. Market-based pricing or continuous payments of instalments may prove valuable to capture the identified new value. Neither were generally utilized by the residential real estate cases, as shown in Table 19.

7.4 Implications of the Business Model Innovation Study

The approach to outcomes-centered business models can help address managing the risk associated with current, systemic housing issues such as those mentioned in the Joint Center of Housing Studies (2019) to ensure effective housing. A number of examples are subsequently discussed to illustrate the potential benefits of deconstructing business models for innovation.

Companies who lend physical assets may capture rent differently to relieve the cost-burdened renter, for example, by changing or trimming cost structures to accommodate for revenue loss or pricing models. Value-based pricing models may provide flexibility for renters and landlords. For example, rent payment may be lower at times of high expenses for renters (e.g. school shopping, and holidays) yet still allow landlords to meet financial obligations. Value-based pricing models may incentivize mutually beneficial rental agreements. To elaborate, businesses can change small portions of their BMs to accommodate for loss of revenue without changing their essential business. Similarly, most of the companies studied herein manufacture services. These business models may be modified to provide the additional services to needed for low-income households complementary to current operations. The key is to streamline and trim down cost structures. Since low-income households are unlikely to contribute additional revenue, owners need to take advantage of economies of scale and pursue more strict cost control to create and sustain value. In this instance, efficiency will be the top competitive driver. Some other residential real estate businesses may be able to learn from Welltower's BM to capture opportunities to meet the needs of fixed-income households like the aging population. Separately, companies involved in the home-purchase process like Zillow, Realogy, and lenders can improve economic education and counseling for potential homebuyers and provide access to safe and affordable mortgage financing. For example, Realogy could provide economic education or counseling (i.e. historical or future market studies, true expectation of short-term or long-term property expenses such as tax and insurance information, appliance and mechanical system information, closing costs) for potential homebuyers enhancing their existing functional value (e.g. like consulting firms such as Accenture or McKinsey on program implementation) and experiential value offerings (e.g. vehicle retailers, Turbotax which provide a friendly solution to less knowledgeable customers) Zillow and other lenders could offer this information to potential borrowers. These changes may support companies like Zillow and Realogy that aim to provide positive experiential value to clients. This information can likely fit into Zillow's Zestimate or Custom Quote platforms. Both companies could expand their direct touch engagement strategies to provide potential homebuyers' convenient access to additional economic know-how. Mortgage companies – connectors of financial assets – can potentially partner with an existing platform such as Rocket Mortgage to utilize their infrastructure. In this example, the seller acts in a broker role and can create an additional revenue stream and mortgage lenders receive more customers in return; similar to how online retailers are partnering with AmazonPay or Paypal for a smoother and trusting payment process for customers.

7.5 Implementing a New Design Paradigm

The outputs of this work can add practically to the current building design paradigm through concerted actions by key stakeholders in the building design, development, and management ecosystem. The systems view of building performance can help researchers investigate the synergistic effects of often independently designed building systems, and the extent of their influence on functional, social, and emotional aspects of whole building performance. This information could be influential to change building codes that drive building technology design goals; closing the human-building interaction and building performance gap. The identification of critical socio-technical, spatio-temporal building consumption factors, longitudinal stakeholders, and shared efficacy metrics can expand the data inputs in building modelling software and refine the LEED rating system innovation metrics mentioned in section 7.2. New definitions of building outcomes, value, and efficacy, shared efficacy metrics, and the (Multi-Stakeholder Longitudinal Building Value Model (MSLBVM) could influence policy design to encourage measurement of building effectiveness. The players in the residential real estate industry and government entities could also work together to determine which of the business model solutions, or solution components, proposed herein may be viable to put forward in whole or in part as new offerings for customers. Further, government entities, contractors, and building design organizations could use the MSLBVM to measure or demonstrate building benefits and costs. Lastly, building owners and other beneficiaries may use the MSLBVM to negotiate design decisions at the outset of a project, and/or highlight or pass on benefits and costs relevant to subsequent owners or other beneficiaries.

The presented holistic, system level view of linkages between design and multi-faceted building performance measures can be embraced, and the longitudinal value realized and made financially viable through deep engagement with the stakeholder ecosystem. The realization of the benefits of the insights gained through this study will require refinement or alteration to current practices pursued by stakeholders at multiple stages of the building lifecycle.

7.6 Limitations of the Research

This research has limitations ushering in opportunity for expansion. A critical limitation of this work is that each research stream was conducted using a single source type (e.g., documentation). Data on the causal relationships between buildings and people can be further investigated to yield comprehensive, dynamic models to understand, predict and monitor how and why building design influences human outcomes/impacts. Therefore, the delineated longitudinal, socio-technical view of the building system may be improved with agent-based or dynamic modeling to investigate “what if” scenarios to assess the effect of varying technical and social variables for the building system and ecosystem. This may require detailing outcome indicators using this conceptual model and existing social, economic, financial, cultural, functional, and behavioral models linked with physical building design parameters. This contribution is limited to US standards and metrics for residential buildings. The literature review on the impacts of buildings on occupants was comprehensive, not exhaustive, and gathered from available information about commercial and residential buildings.

Key limitations of the LDA topic modelling study are the fixed number of topics searched, and the single definition for one word assumption. However, the additional search in phase 2 addressed the need to corroborate and expound results. There are also potential inaccuracies of cost and benefit models because the selected values were not studied in the same context over time highlighting the opportunity for experimental research.

Experimental research may improve quantitative connections between building purposes, contexts, attributes, outcomes, and values may be drawn from understanding stakeholder engagement and its impact on building performance. Sensing technologies and behavioral economics may help understand how consumer behavior is influenced by its environment. The knowledge management scheme may guide building, and technology, design decisions to strategically identify the critical variables and metrics for each stakeholder. The influence of specific design and feature qualities on value dimensions may also be assessed. Financial analyses of the building value may be expanded through 1) research on managing value trade-offs of building attributes for multiple stakeholders as shown by French, Bedford, and Atherton (2005) which may improve cost-benefit analyses of the building value, 2) examination of strategies for dealing with externalities, and application of 3) multi-objective optimization methods.

The BM levers' transferability and methodology limit the results of the business model innovation study. The transferability of analogous business model levers into the research real estate cases would require research into the cost structure, margin model and resource structure velocity for each model. This research limitation deserves further research to prioritize viable levers. This study does not make the claim that selecting one choice of the BM design options will yield specific results due to study limitations. Three limitations are associated with the business model design method employed. First, the interaction between different model components is theoretical and can be further detailed and connected (Liu et al., 2020). Similarly, the effects of BM changes on other models, internally or within the industry, are not captured. Lastly, the interpretation of qualitative data for business model components is from multiple researchers' perspective. Separately, there is a general limitation of the study as it was conducted using a single source type (e.g., documentation). Research engagement with residential real estate industry players can help map the micro-behaviors, norms, and practices of the industry and the underlying factors affecting the motivations and decisions of each player that affect the level of investment in effective building development. Network metrics and analysis can quantify the significance of each player in terms of their effects on the potential of financing building innovation. Therefore, an opportunity remains to refine and test the proposed potential business model components.

This research does not claim that one choice will yield specific results and was conducted to spur strategic, intentional pursuit of new innovative opportunities in building design. The author also recognizes that reviewing the literature before developing assumptions, for the study structured using grounded theory, lowered the safeguard for potential biases that may threaten the objectivity of the system-view of building performance.

7.7 Conclusions

Innovation is critical in sustainability, green building systems, and energy efficiency (GhaffarianHoseini et al., 2013). The highest innovation potential is at the system level, where the positive system synergies can be exploited (Hensel, 2012). Human activity is at the center of the agent synergies and building design innovation opportunities, suggesting that the benefits of buildings are multi-dimensional, and the buildings sector is primed for innovation predicated on attending to stakeholders' needs. Design is a goal-oriented activity. If the goal of the solution shifts, then the solution space changes. The building is an open, socio-technical complex system. Therefore, the building energy problem is a complex problem that is influenced by more than a single performance metric connected to human impacts. However, existing design methods and metrics do not fully capture or quantify the complex synergies that emerge during operation. This work provides initial insight into understanding the system and ecosystem complexity, connecting agents to outcomes, and identifying opportunities to close performance gaps.

This research employed a design science approach to frame a plan to strategically pursue building innovation systematically. Issues disabling the widespread adoption of building energy-efficiency solutions revealed the common theme of a disconnect between building outputs and outcomes. Implementation science aided in detailing the path envisioned for innovation and to re-orient the building energy-efficiency problem. This work presents a logic model to represent and delineate the boundaries of the human-building interaction, and the concepts of the building system, its efficacy, and effectiveness, as support for a holistic perspective of building performance. In essence, crucial building energy-efficiency issues in the current paradigm and influential factors are seemingly unrelated but connected to the buildings' longitudinal value. Application of the ETF behaviors revealed building innovation efforts that directly influence the longitudinal value of buildings can lead to enhanced whole-building performance.

An inductively developed systems view of building performance theory led to a framework grounded in the beneficiary perspective. An evidence-based thematic analysis of ten deconstructed residential real estate industrial models established the state of practice in the building ecosystem. An evidence-based thematic analysis of two separate deconstructed business models unrelated to buildings provided inputs to analogical business levers to practically produce effective buildings. Business model opportunities in the building ecosystem may position the industry for growth if integrated, impactful building system solutions were pursued.

A building performance framework that can serve as a lens for combining perspectives on building performance from technical and social disciplines was also presented. The knowledge management scheme proposed is a structure for building performance innovation and research to identify and quantify influential variables related to different contexts, purposes of buildings from the stakeholder perspective, and end-user metrics. This model presents a mechanism for building performance modeling to predict and measure the effectiveness of buildings and corresponding solutions. Current and new research into different building attributes and their impacts can be organized into this knowledge management scheme to identify design, performance, and related policy gaps. Application of the means-end model provides a new mechanism to categorize and group buildings and array them into sets based on their possession of attributes that imply the ability to provide desired outcomes for the consumer. Also, this model would be useful for value management and impact-focused building design to promote equitable, healthy, safe, and sustainable buildings. This research should prove instrumental in researching factors that impact building performance and in determining performance levels as well as supporting the work of practitioners and building technologists by providing a measure to achieve high-impact, targeted design and innovation.

This longitudinal view of value creation provides a foundation to study the transferability of value across the ecosystem. Design and development decisions pertaining to this socio-technical, complex system produce system attributes that yield outcomes and impacts, and provide a nexus to connect longitudinal benefits and costs for potential realignment.

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APPENDIX A. APPLICATION OF THE ENABLING THINKING FRAMEWORK OVERVIEW

This framework is comprised of stage-specific design behaviors and patterns critical to achieving impactful innovations (see Tables B1, C1, D1), and these were employed to guide the identification of paths to improving building system and subsystem design. However, this design science approach demands diverging, converging, and applying ideas from different knowledge bodies to the problem at hand. On this note, Table E2 describes the various foundational concepts and their application to framing building performance.

A systematic, end-to-end innovation strategy is required for the development and evaluation of impact-focused building solutions. Therefore, the ETF was applied to advance this effort by reshaping the building energy-efficiency challenge, offering a longitudinal perspective of building performance. In the first step, the potential for building performance improvement through innovation, and building performance gaps for the single metric of energy-efficiency as an example analysis were systematically assessed. A roadmap to guide on-going innovation efforts was established in Appendix B as one does not exist in the literature following the ETF design behaviors in Table B1. Then, the building energy-efficiency problem was re-cast to expose underpinning assumptions of the existing paradigm which may be crippling the achievement of higher levels of building energy-efficiency in Appendix C following the ETF design behaviors in Table C1. The second step was to propose a view to close performance gaps in Section 4.

A building innovation roadmap was envisioned in Appendix B by 1) assessing the pattern of emerging trends supporting the opportunity for building innovation, 2) foreseeing the potential impact cascade of building innovation, 3) assessing potential starting points for low-resistance to building innovation, 4) defining metrics to evaluate the success of an idea, and 5) imagining the long-term opportunities for whole-building performance improvement. The ETF includes the Enabling Innovation Model (EIM) which promotes the strategic management of innovating for impact by characterizing the effect of innovation based on its level of reach, areas of significance, degree of paradigm change and longevity (Solis & Sinfield, 2015). The potential impact cascade of building innovation was visualized and discretized after review of the 2018 International Building Codes (International Code Council, 2019) and sustainable design metrics using the EIM as shown in Figure B1.

APPENDIX B. ENVISIONING A PATH REIMAGINE BUILDING PERFORMANCE

Table B1: Envisioning Stage Design Actions

Behavior	Definition	Descriptive actions
Define the opportunity space	To identify and describe a pattern of changing trends that suggest the potential for achieving enabling impact	• State the overarching goals or visions • Articulate innovation opportunities
Identify blind spots and in-going biases	To acknowledge biases in judgment and theme areas that are not fully understood and can affect the opportunity space	• Create lists of assumptions, unknown factors, and personal biases • Structure the assumptions • Define possible blind spots and gaps
Foresee the impact cascade	To visualize the dimensions of impact	• Itemize potential impact areas that may be addressed by an innovation • Estimate the potential reach of an innovation • Express the possible paradigm changes due to an innovation
Envision a performance-application roadmap	To acknowledge application spaces that materialize as the performance of a concept improves	• Create initial forecasts of performance development and broad impact spaces • Characterize the relationship between performance development and the gap of new possible impact spaces
Define success metrics	To outline metrics by which an idea can be evaluated throughout different design stages	• List success metrics for each stage, context, desired performance, and desired impact • Identify data sources and evaluation procedures to carry out measurements
Test and select entry points	To determine possible starting points in the problem and solution development	• List possible entry points (e.g. ecosystem, problem, solution, stakeholders) • Assess paths of least resistance to impact and momentum for each entry point • Take long, medium and short-term perspectives

As guided by the ETF model, in this work, a path for building innovation was envisioned following the design behaviors in Table B1 as found in Solis & Sinfield (2018). The opportunity space for building innovation was supported by growing, impact-centered trends which suggest this is the opportune time to reimagine building design and performance to comprehensively address occupant and owner needs. Five exemplary trends include: 1) Coronavirus (COVID-19) pandemic, where building use and stakeholder needs have taken a dramatic shift, in some cases pushing human and building limitations, directly influencing many lives and livelihoods across different contexts and a likely permanent shift in building use patterns, 2) the industrial trend from product-focused to product-service system (PSS) models that improve user and manufacturer outcomes, improve sustainability and the value for the customer and are increasing expected in all contexts including buildings (Fargnoli et al., 2018) (Accenture.com, 2019), 3) the digitization and technological integration in the building sector to improve user outcomes, 4) shift across the public and private sectors to enhance user well-being (Donato-Capel, 2018) and employee well-being (Morgan, 2015) (Agarwal et al., 2018), and 5) the building sector shift toward ecosystem-level changes to enable performance-based design (e.g., LEED, and WELL buildings; and performance-based contracting). Given these trends, the design innovation potential is in enhancing downstream stakeholder outcomes through a systems-oriented view of the building; shifting the design paradigm from a modular to integrated offering (Baldwin & Clark, 2000) (Schilling, 2000) (Galvin & Morkel, 2001) (Mikkola, 2006) and potential solutions from sustaining innovations toward enabling/disruptive.

The current and potential impact dimensions from building innovation were visualized and discretized after review of the International Building Codes (International Code Council, 2019). and sustainable design metrics (U.S. Green Building Council, 2020) using the Enabling Innovation Model (EIM) as shown in Figure B1. The EIM promotes the strategic management of innovating for impact by characterizing the effect of innovation based on its level of reach, areas of significance, degree of paradigm change and longevity (Solis & Sinfield, 2015). Applying this comprehensive, generalized model of impacts to buildings framed building performance in terms of its impact and provided a preliminary map of design gaps and innovation opportunities. The reach of general building innovation is vast due to the number and types of buildings; however, the reach of specific innovations should be estimated. The potential significant areas building innovation can simultaneously influence include occupant outcomes - health, well-being (including an economic component), and human performance (e.g., education, work productivity) - environmental outcomes (e.g., minimal building carbon footprint), and business/building owner economic outcomes (e.g., profitability, and economic growth). On that note, the possible paradigm shift supported by the path for building innovation offered in this paper is toward the development of buildings (and their technologies) that achieve building-level metrics and improve beneficiary outcomes.

Metrics to predict or measure the success of an innovation can be strategically achieved by specifying a type of innovation impact to guide the design process in design briefs (Solis & Sinfield, 2015). The design process starting point can begin in the problem or solution space; at the component, system, and ecosystem level; and aiming to achieve minimal resistance and increase chances of adoption from beneficiaries. The strategic success of innovation, the potential of a solution to achieve the goal/impact should consistently be evaluated throughout the design process; in doing this, ideas are targeted, not limited. Therefore, building innovation metrics should 1) address critical beneficiaries in the building design and development stages, 2) mitigate originating stakeholder bias, and 3) balance tradeoffs among beneficiaries. It is also essential that building innovation pursuers recognize their blind spots and in-going biases and formally mitigate them in their selected design process. Building performance improvements can be monitored in the long-term using two approaches. First, the current building performance metrics (e.g., the International Codes and whole-building design metrics) can serve as a baseline to map progress over time toward improved performance in the potential building impact areas for buildings Figure B1. Second, possible solutions to ecosystem-level building performance can be borrowed, tested, and developed in/from other similar application spaces with similar problem characteristics. For example, the airplane industry (Gray, 2017) and public health (Hanefeld et al., 2017) face similar problems: the development metrics of products/processes are spatially and temporally disconnected from their effects on end-users.

Building design innovation should focus on creating and implementing ecosystem-level strategies for improved building performance. Building innovation that addresses the ecosystem-level problems is likely to lead to a low-resistance, high impact, and high momentum path for building innovation for several reasons: 1) building-level and component-level issues should be inherently resolved, 2) systems-level approaches support performance-oriented design have the highest potential for innovation in architectural design and sustainability due to the exploitation of synergies (Hensel, 2012), 3) the possibility to influence building performance is highest in the early design stages and decreases dramatically overtime (Kohler & Moffatt, 2003), 4) system design choices can affect and shape downstream end-user decisions (Proctor, & Van Zandt, 2008, p. 291), 5) ecosystem approaches are recommended to manage the complex challenges of sustainability (Kay et al., 1999).

		Areas of significance			
		Economics	Environment	Health	Culture
Levels of Reach	Individuals	Income	Livability	Physical health	Lifestyle & habits
		Nature of work	Control	Social health	Education
		Efficiency	Security	Emotional health	Values
			Mobility		Sense of identity
	Groups	Businesses	Spaces	Community health	Org. structures
		Value networks	Facilities	Social networks	Org. interactions
		Productivity	Connectivity	Sense of belonging	Collective knowledge
					Shared beliefs
	Society	Financial resources	Resource availability	Public health	Policy/government
		Economic growth	Climate change	Well-being	Demographics
		Output	State of infrastructure		Body of knowledge
		Trade	Ecosystems		Cultural norms

Hypothesis:
Likely addressed in building design
Not likely addressed in building design

Figure B1: Initial hypotheses of missed building impacts

APPENDIX C. SHAPE A PATH REIMAGINE BUILDING PERFORMANCE

To address the building-level innovation gap, a grounded theory logic was applied to reframe building performance by applying the design behaviors in Appendix C 1) framing the flaw in the paradigm, 2) seeing the systems, technical, economic, socio- and psychological forces, broadening idea spaces by connecting generalized first principles, 3), addressing host ecosystems, 4) and rethinking performance and connecting it to early impact contexts. The building energy-efficiency problem was reframed by searching for a flaw in the current building design paradigm, and accounting for the systems, technical, economic, socio- and psychological forces that influence building energy consumption. First, the current building design and use paradigm was structured and questioned using a mental model to conceptually clarify the ambiguous nature of the complex problem. The Mechanics-Dynamics-Aesthetics (MDA) framework was employed to frame the flaw in the paradigm and ask "why" and "what if" questions about the current building design paradigm, and expose hidden assumptions and a means to observe opportunities in latent, yet amiss, assumptions on which the paradigm is predicated. As a result, a flaw in the current paradigm and innovation opportunities were recognized. Physical evidence of this fundamental building design flaw was supported by a peripheral preliminary investigation.

Table C1: Shaping Stage Design Behaviors

Behavior	Definition	Descriptive Actions	Actionable Principles
Define problems: Spot opportunities in flaws	Recognizing opportunities in flawed yet latent assumptions that underpin paradigms	• Search for anomalies/gaps within an idea space • Interpret/explain insights that are seemingly anomalies/flaws • Integrate/articulate hidden assumptions in synthesis activity	• Separate mental framing from accepted practice • Separate problems from solutions • Break problems and solutions into components and attributes • Assess rationale for links between problems and current solutions • Identify what is done by cultural norm rather than by absolute necessity • Focus on flawed norms and proactively consider different perspectives
Define problems: Question the paradigm	Asking "why" and "what if" questions that reveal a paradigm's hidden assumptions	• Asking questions about current norms or aspects of the working paradigm • Wondering why things are done in a certain way in a specific context • Asking "why" and "what if" to unearth new paradigm possibilities	• Ask technical and economic systems, and socio-emotional systems "what if' and 'why' • Differential between negotiable norms and non-negotiable rules • Probe to uncover second and third order effects • Differentiate answers that satisfice from those that merit further exploration • Understand when it is important to probe further and be willing to act on learning

Table C1 continued

Define problems: Structure ambiguity	Providing logic to ambiguous, complex, and ill-structure problem and solution spaces	• Creating an issue tree or influence diagram that provides structure to an ambiguous problem or solution space • Defining and naming categories of ambiguous ideas • Employing a framework that helps capture all aspect of a complex problem-solution space	• Break ambiguity into unknown and known knowledge gaps • Assess uncertainty and significance of knowledge gaps • Provide a tree structure to knowledge gaps by asking why or how • Diverge, structure, converge exploring issues at varying levels of depth • Iterate between inductive and deductive approaches to structuring • Ensure that structure is mutually exclusive and collectively exhaustive

Table C1 continued

Gather Information: Create empathy-based mental models	Create mental models that account for the behavior of technical, economic, systems, sociological or psychological phenomena from self, other, cognitive or affective immersive experiences	• Create personas or profiles of stakeholders or end users putting yourself in the place of others intellectually or emotionally • Describe empathy-resembling mental models of how artifacts or physical phenomena interact with each other	• Map actors, objectives, and circumstances • Identify techno-economic, systemic, and socio-emotional interactions, tensions and barriers • Create an empathetic mental model of linkages and root causes of tensions and barriers • Assess if links and root causes are rules, norms or assumptions to search for hidden insights • Play with the mental model to unfold second or third order effects that lead to new insights • Identify any in-going biases that have may informed mental model

Table C1 continued

Gather Information: Notice forces at play	Proactively perceive all possible significant influences in a given situation based on hypotheses, prior experiences, frameworks, changes, or unanticipated patterns	• Being intentional/systematic in recording observations • Employ frameworks or hypothesis to search for implications/forces • Search for noticeable differences compared to prior experiences or knowledge	• Consider technical, economic, systems, social, and emotional forces • Diverge, structure and converge on the forces to monitor • Create a working hypotheses that account for all forces at play • Establish most likely conditions to be encountered in a circumstance • Monitor and focus on unanticipated signals that deviate from most likely conditions • Reflect to uncover second and third order effects of findings on hypotheses

Table C1 continued

Gather Information: Observe diverse circumstances proactively	Engage in constant observation across diverse circumstances to inform and observe hypotheses	• Mention cases/situations that would be ideal to observe • Suggest ethnographic activities to engage	• Develop a basic awareness of things to look for • Create an inventory of relevant contexts and circumstances to observe • Prioritize key circumstances to be observed according to the goal • Recognize elements of each circumstance, context, situation • Become aware of in-going biases
Generate Alternatives: Interact with new schools of thought	Obtain and test ideas through many types of interactions across counterintuitive contexts or at the intersection of fields	• Attend events/conferences outside of ones discipline/field • Talk to people from counterintuitive domains • Proactive social interactions with people outside one's discipline/field • Proactive exposure to information outside one's field/discipline	• Translate domain specific ideas into generic language • Seek different perspectives by breaking away from usual social network • Push ideas across many contexts and a testing mechanism • Pull ideas from exposure to non-traditional environments • Suspend judgment, reflect and engage in objective dialogue • Synthesize learning from network exercises

Table C1 continued

Generate Alternatives: Explore morphological combinations	Explore all possible idea variants that result from combinations in the identified features/aspects of problem and solutions spaces	• Create a comprehensive perspective of possible combinations of ideas • Test idea combinations and their implications	• Break down a concept into its core components and attributes • Diverge, structure and converge on the forces to monitor • Create a comprehensive, systemic view of combinatorial possibilities • Understand the morphological possibilities that are within a set of established goals and bounds • Link and explore all combinatorial possibilities even if counterintuitive

Table C1 continued

Generate Alternatives: Link core ideas to problems and solution spaces	Find cause-effect patterns in problem and solution spaces by noticing trends that are seemingly unconnected	• Connect ideas across contexts/spaces • Thinking of analogies for problems or solutions at hand • Connect underlying principles between ideas in separate fields	• Decompose problems and solutions and identify core components in target contexts • Find the first principles underlying core problems and solutions • Separate problem and circumstance using generalized descriptions • Identify source ideas to connect in analogical, opposite, intersectional and adjacent domains, identify aspects of solutions in source contexts that transfer to target context • Decide if a solution or aspects of it are applicable, translate and adapt
Model and Analyze: Map ecosystem elements	Mapping system elements to understand its interactions at different levels of analysis	• Name the components of a system • Attempt to understand the relationships between system components and the different levels of system depth	• Decompose a challenge into systemic components • Identify system components, linkages, stakeholders and boundaries • Employ a representation method that matches the needs of the challenge • Consider links to other ecosystems • Request input from key stakeholders that enhances system understanding

Table C1 continued

Model and Analyze: Model future ecosystem states	Understand future possible ecosystem scenarios and the implications of such scenarios and the implications of such scenarios for present-day innovation efforts	• Envision/imagine future states in an ecosystem, • Explore the implications of future states for the present states • Engage in "backwards design" types of activities in which possible future ecosystem states guide design activities	• Identify future scenarios and parameters to be modeled • Create models of future ecosystem scenarios considering the influence of prior states • Assess technical economic, sociological and psychological implications • Alter parameters, change assumptions and explore second and third order effects • Derive the implications of future ecosystem states for present day efforts
Model and Analyze: Porpoise	Knowing when first, second, and third order effects are important	• Switch between system perspectives and "deep dives" into analysis • Iterations between broader problem perspectives and details in each problem/solution components to search for logic in gaps	• Explore components using an intuitive understanding of them • Zoom into components and explore implications of the next level of analysis • Explore subsequent levels of depth until returns diminish • Drill down to an actional level of detail • Analyze implications of in-depth analysis at the systems level • Alternate between "deep dives" and systemic perspectives

Table C1 continued

Model and Analyze: Reconfigure ecosystem nodes, links and exchanges	Design solution components that potential to influence the configuration of ecosystem components/nodes and links	• Describe how elements of an ecosystem could be reconfigured with the introduction of a solution • Describe possible changes to an ecosystem that could facilitate the adoption of an innovation	• Map possible components and links that can be reconfigured across ecosystems • Identify possible modifications: separations, combinations, relocations, additions and subtractions • Employ multiple lenses to understand the implications of ecosystem configurations Attempt to understand systemic emergent behaviors
Evaluate and Select: Identify performance dimensions	Create a mutually exclusive and collectively exhaustive perspective of technical, economic, psychological, and sociological dimensions of performance	• Explicitly identifying dimensions of performance • Explicitly identifying scope for improvement	• Decompose a challenge into key performance dimensions • Identify performance dimensions of current state of solution • Employ technical, economic, systems, social, and emotional dimensions of performance • Describe performance dimensions using generic language for use across contexts • For each dimension, assess its headroom for change in the future • Prioritize dimensions of performance to be advanced based on enabling window goals

Table C1 continued

Evaluate and Select: Characterize application contexts	Create a perspective of reach, significance, and paradigm change that can be pursued and the performance requirements in a given context	• Explicitly identify contexts and relevant dimensions of impact • Explicitly characterize contexts in which solutions will participate	• Diverge, structure, and converge on an list of contexts in which a solution could play a role • Break down each context or impact space into its key components • Consider contexts outside historical norms proactively • Identify the performance dimensions and profile of commonly employed solutions • Identify the reach, areas of significance and paradigm change required to play a role in such a context • Prioritize impact contexts according to performance development and impact benefit potential

Table C1 continued

Evaluate and Select: Map accepted and counterintuitive tradeoff combinations	Evaluate possible variation in dimensions of performance in an idea, including counterintuitive dimensions	• Comprehensively map combinations in performance dimensions • Explore different lever/variable configurations	• Identify all possible tradeoff combinations in a solution • Search for dimensions of performance overlooked in a working paradigm that are relevant to a new paradigm • Define what excellent and acceptable means in new and working paradigm • Lower performance in unimportant new paradigm dimensions to “acceptable” • Increase performance in dimensions that stem from the emerging paradigm • Search for misalignment between capabilities and contexts that may be stifling progress
Evaluate and Select: Match lily pad contexts with tradeoffs and headroom	Connect solution to contexts that embrace a given set of tradeoffs, even if outside of traditional expectations and boundaries, to accelerate impact	• Match performance tradeoffs with contexts that might find such tradeoffs desirable • Create performance-context roadmaps for the evolution/development of an enabling innovation	• Remove artificial ties to contexts via generalized language to make matches • As “for whom is my concept good enough or adequate”? • Identify contexts that might embrace the current tradeoffs of a solution • Identify the “lily pad” benefits an evolving concept would gain from a context

Framing the flaw in the current building design paradigm

A logic was applied to organize the problem and solution spaces of current design challenges, a vehicle to ask "why" and "what if" questions about the current paradigm to expose hidden assumptions, and a means to observe opportunities in latent, yet amiss, assumptions on which the paradigm is predicated. Conceptual application of the MDA framework (Hunicke et al., 2004) in the building context, defines the mechanics of the building system as the rules and concepts that specify the system (e.g. building components, design, and development activities), the dynamics are the time-based behavior of the mechanics induced by user inputs and component outputs, and the aesthetics are the evoked responses due to building use. It served as a mental model to structure the ambiguity in the current building design paradigm. There was difficulty in answering questions such as "Why do people engage with buildings?", "If physical building factors or human factors change, how will that impact building performance?" and "How can the building be modified to and improve user outcomes?" Consequently, this exercise revealed two potential avenues for building performance improvement - change the design behavior or occupant behavior, and the disconnect between building design mechanics and its aesthetics (e.g., outcomes); the underlying flaw. Since humans do not necessarily want to change their building-related behaviors (Alabama A & M University et al., 2011) (Frederiks et al., 2014), and the building inherently influences human behavior this research informed changing the building design philosophy. Building beneficiaries' outcomes were considered in lieu of the user outcomes in the general MDA framework.

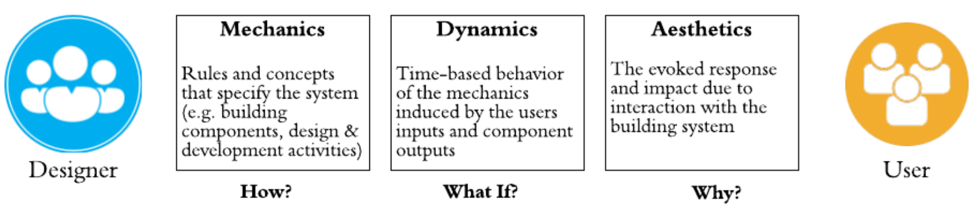

Figure C1: Visualization of MDA framework in the building context

The identified building design flaw - the disconnect between building design outputs and outcomes – was evaluated by investigating if current building design standards fully capture two outcome-related, building performance sub-metrics (under the current paradigm): indoor air quality and thermal comfort. The in-situ impact of physical building factors on the outcome-related sub-metrics were assessed using the Python tree-based feature selection (Pedregosa et al., 2011) on data from an office at the Ray W. Herrick Laboratories. This Python feature is a method of learning by assessing the causal relationships between parameters using decision trees. The extra trees regressor implements a meta estimator that fits a number of randomized decision trees on various sub-samples of the dataset. The feature importance function weighs the importance of features on a specific variable (Pedregosa et al., 2011).

Thermal Comfort

Thermal comfort was calculated using Fanger’s model (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2013) for a range of data and is shown in Figure C2. The importance of measured parameters on thermal comfort was assessed. The metabolic heat rate (M), space temperature (dry bulb), and mean radiant temperature (T_{MRT}) were the top three important variables at summing to approximately 99% of importance and are captured in Fanger’s model. The space temperature at the façade, the outdoor air (OA) temperature, and the outdoor air relative humidity followed in importance. The space temperature at the façade likely captures the strong influence the space temperature on the predicted mean value (PMV) value. The supply air (SA) temperature was not important. These results were expected.

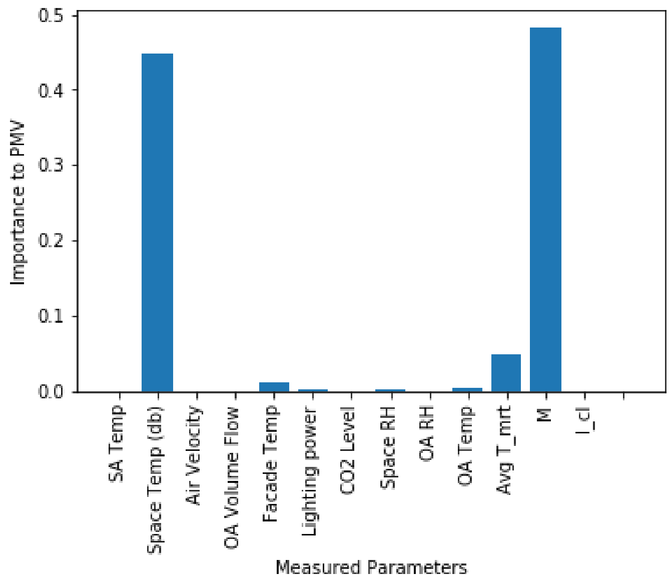

Figure C2: Importance of Measured Parameters on Thermal Comfort

After removing the top two variables, the importance of the mean radiant temperature compared to other variables was apparent and the air velocity increases in importance as shown in Figure C3. The outdoor air temperature, space relative humidity and outdoor relative humidity followed the façade temperature in importance. The space relative humidity is captured in Fanger's comfort model by the partial pressure of water vapor in the air. The outdoor relative humidity and the outdoor air temperature are not addressed in Fanger's thermal comfort model. This could provide insight into the relationship between thermal comfort and improved satisfaction with fresh air independent of it is brought in through mechanical or natural ventilation.

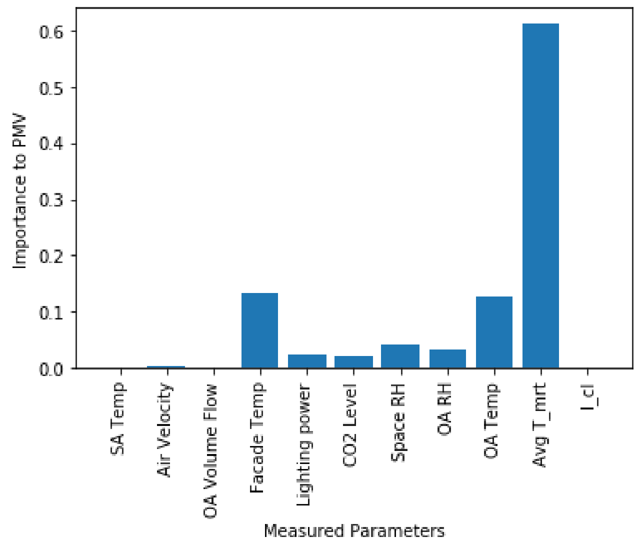

Figure C3: Importance of Measured Parameters on Thermal Comfort without Top 2 Variables

Indoor Air Quality

The outdoor air flow rate per person relationship to carbon dioxide (CO_2) for acceptable indoor air quality is related in ASHRAE Standard 62.1. The outdoor air flow rate per person is a function of the CO_2 generation per person, CO_2 concentration in the space, and the CO_2 concentration in the outdoor air. The CO_2 concentration in the space is measured and the CO_2 concentration in the outdoor air can be collected from weather data. The top three variables of importance were the space temperature, lighting power, and slab temperature at 18.2%, 17.7% and 12.8% respectively as shown in Figure C4.

The importance of the lighting power may be due to occupancy. The lights are on in the presence of occupants, but occupancy was not recorded. The CO_2 generation per person directly impacts the CO_2 concentration in the space. However, Sterling & Sterling (1983) explicitly studied the relationship between lighting and mechanical ventilation on indoor air quality. Perceptions of lighting quality were higher when lighting and ventilation were both changed as opposed to lighting only. Lighting only changes improved mood and reduced irritability. Simultaneous changing lighting and ventilation composition reduced eye irritation, headaches, sleepiness, irritability, and improved mood and concentration. Moreover, eye irritation complaints decreased when lighting changes were coupled with changes in the composition of ventilation air. The authors hypothesized that eye irritability in many offices may be due to the indoor photochemical smog which is a build-up of photochemical by-products and this build-up is accelerated when light contains ultraviolet emissions and that ventilation near fixtures may reduce smog. The indoor temperature importance is due to the pressure-volume-temperature relationship for organic compounds. The importance of the slab temperature is likely to its role as the air heating source but could also be due to surface radiation. The outdoor CO_2 concentration followed in importance. This aligns with the relationship outlined in ASHRAE Standard 62.1. The space relative humidity, outdoor air temperature, preheat coil temperature, and the outdoor air relative humidity followed in importance at 10%, 9.0%, 7.7%, and 8.7% respectively. There four variables are not considered directly in the relationship outlined in ASHRAE Standard 62.1. The space relative humidity is likely due to the pressure-volume-temperature relationship for organic compounds. The preheat coil is the first mechanism to interact with the outdoor air and raise the outdoor air temperature which highlights its importance. The importance of the outdoor air temperature, preheat coil temperature, and the outdoor air relative humidity show the dependence of the indoor CO_2 level on the outdoor air properties. The volume flow of outdoor air brought in and the total volume flow of air into the space (the sum of air volume A and B) sum to an importance of approximately 5.1%, least of all the variables. As bringing outdoor air into the space is the primary means of removing indoor contaminants, the focus is generally on the volume of air exchanged as opposed to the properties of the air because the outdoor air properties are uncontrollable.

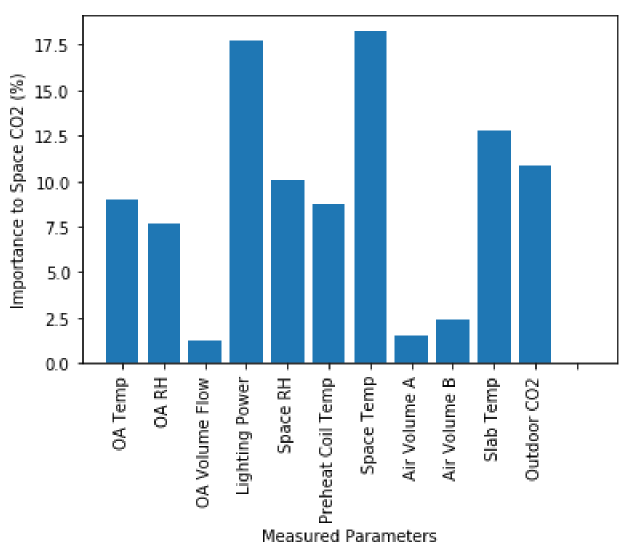

Figure C4: Importance of Measured Parameters Space CO_2 Level

An opportunity for innovation was spotted from the flaw in the current paradigm that can be exploited for improved whole building performance. Both analyses exposed the importance of the outdoor air properties to thermal comfort and indoor air quality; explaining many of their synergies. In current design practice, outdoor air exchanged through the building envelope is reduced to save HVAC system energy; however, indoor air quality is compromised because less contaminants are flowing out of the building. The best design strategies balance the two where the volume of conditioned outdoor air is balanced with energy-efficiency and its IAQ is estimated. Nevertheless, there is an opportunity to minimize the need to tradeoff by exploiting this outcome-related synergy by creating solutions that provide the outdoor air quality benefit, and moving away from the energy-intensive practice of conditioning volumes of outdoor air.

This preliminary analysis revealed that the spatial interactions between parts provides an opportunity for innovation to develop new solutions that achieve enhanced system-level performance. It would be beneficial for further research to quantify the system-level interactions between building systems and their influence on human-related metrics.

See the systems, technical, economic, socio and psychological forces

Methodical review of the influence of these forces on building energy consumption highlighted the: 1) spatiotemporal property of building energy consumption, 2) interdependencies on environmental factors, 3) interdependencies on resource allocation decisions by the occupant, owners, and designers, 4) the building is a complex system, 5) the building is a socio-technical system across its lifetime, 6) the multi-sensory impact of the built environment on humans is a complex problem, 7) there are various counterintuitive occupant factors unrelated to the building physics that impact building energy consumption, 8) the human-building relationship for non-occupant beneficiaries is initiated by value sought; this can be an economic metric or a physical performance metric (e.g., resilience, energy-efficiency, wellness) and conflicting performance criteria and development strategies can complicate exceeding minimum performance standards. The systems, technical, economic, and sociological forces present in building-energy efficiency revealed the complexity in the interactions between building variables, suggesting that the technical design of building energy systems should be because of their integrated, meaningful capacity (e.g., relative to building-level human and technical standards). Recognition of these forces also supports a perspective of building energy-efficiency as a socio-technical output and developing solutions that intentionally capture the diversity of building variables and outcomes. For example, its energy performance is dependent on other non-energy consuming systems. Similarly, energy-efficiency is dependent on different performance metrics.

The influences on the technical and human challenges to building energy-efficiency were methodically assessed for premeditated solution generation in which the systems, economic, sociological, and psychological forces that influence building energy-efficiency are aforethought. Technological barriers and human barriers to building energy-efficiency were examined. First, systems information about the component physical (energy) interactions and technological challenges was gathered. Then, drivers and inhibitors of human-building interaction relative to building energy-efficiency from the occupant and non-occupant perspective were reviewed to yield a stakeholder-centered viewpoint of challenges. Collectively, this information conceived re-orientation of the building design and performance in a new lens from an exemplary single performance metric.

The Physical Perspective of Building Energy-Efficiency

The physical variables associated with the building energy use were evaluated to frame the initial system-level perspective of building energy consumption from a bottom-up approach. The building envelope, heating and cooling equipment, appliances, cooking, occupancy, and lighting were considered in the analysis. In summary, the differential pressure between the indoor and outdoor environment causes mass transfer at a temperature containing a quantity of heat per unit mass across the building envelope; and the physical variables associated with air, moisture and heat flow through the building envelope is well defined by Hens (2012). The volume of air exchanged with the outdoor air recoups the thermal energy lost through natural ventilation, infiltration and internal heat gains and is conditioned by the HVAC system. Three palpable themes from this review were: 1) the spatiotemporal property of building energy consumption, 2) the interdependencies on environmental factors, 3) the direct dependencies on occupant and early design decisions. The spatiotemporal properties were evident in the physical thermally-related variables. Mass flow and temperature gradients are dependent on location and change over time. The interconnectedness of physical thermally-related variables with environments led to the deduction that, potentially, the building is a complex system, and therefore, its energy performance is dependent on other non-energy consuming systems, other performance metrics, and occupant thermal and behavioral characteristics. Also, many environmental variables result from resource allocation decisions made during any stage the building life suggesting the notion the building is a socio-technical system.

The complexity of energy demand from a physical perspective is illustrated in 9. Emergent behavior as a result of the dynamic interactions between physical environmental factors (e.g. fenestration, internal loads, mechanical systems, water flow mechanisms, and air movement mechanisms), and personal factors (e.g. human thermoregulation) may explain the disconnect between predicted/designed and realized building energy consumption.

Challenges of Building Energy-Efficiency Technologies

Technological challenges with building energy-efficiency were summarized from the IEA (2013). In summary, there were repeated recommendations for systems and integrated approaches to building energy reduction; the development, commercialization and deployment of promising energy-efficient and cost-effective (e.g. reduced capital or operating cost) technologies; targeted research and development investment to improve efficiencies and cost-effectiveness of potential technologies particularly to improve system-level capabilities; and increased adoption of highly-efficient practices and technologies especially those with beneficial system-level capabilities.

The Stakeholder Challenges to Building Performance

Current definitions of high-performance/sustainable buildings serve to help buildings reach their potential in improving the health, comfort, and productivity of the occupants. This HPB metrics in this definition are not centered around paths to achieving improving the health, comfort, and productivity of the occupants or enabling the stakeholders in the decision-making process to do so. The building systems are designed to meet technical performance objectives, however they have an indirect or direct impact on humans throughout the building life and these tangible and intangible impacts are unclear. The human system interacts with the environment through the sensory system, is received by the perceptual system, and can affect the circadian system. The human sensory system is part of the nervous system is a complex network of nerves and cells that coordinate the actions of an organism by transmitting signals to and from different parts of the body. Using a weak electrical current, the nerve cells, or neurons, receive information from the environment through receptors and send that information through neural pathways from the body to the brain. The brain processes the information and motor neurons transmit the message from the brain to control voluntary movement and trigger the reaction. Sensation begins when a physical stimulus contacts the sensory neurons. Receptors or sensory neurons detect physical energy in the environment such as light, sound, odor, taste, pressure and heat and transform the physical stimuli into trains of nerve impulses in the afferent nerve fibers that innervate the receptors (Møller, 2003). Heat and cold, noise and vibration, lighting conditions, and atmospheric conditions are examples of the physical stressors that directly affect the human central nervous system via changes in sensory receptors (Proctor & Van Zandt, 2008). The level of stress induced by a physical variable is dependent on individual differences/preferences, possibility of control, the person's cognitive appraisal of the situation, and the presence of other stressors. The effect of a stressor can be amplified in the presence of other stressors (Proctor & Van Zandt, 2008).

Senses are the entry to perceive the world. The sensory information can be used by design engineers to influence how occupants perceive and react to their environment. Human performance, health and safety are not determined solely by the design of displays, controls, and their workspace but also habitable areas are often designed to minimize harmful four environmental variables (i.e. lighting, noise, vibration and climate) (Proctor & Van Zandt, 2008). These variables are often compounded in the built environment and can be the source of stress which can have harmful physiological and psychological consequences. In order for an organism to operate effectively within any environment - natural or artificial - it must be able to receive information about that environment through its senses, act on that information, and perceive the effect of its action on the environment (Proctor & Van Zandt, 2008). Humans will receive information about the environment, act on that information, and perceive the change the due to the action. The aggregate impact of these environmental variables and information quality on occupants throughout the building life or the occupant's engagement with the building is unclear. The levels in which building design models and standards holistically address these impacts is ambiguous.

The physical environment in which a human works and lives significantly affects their quality of life. Therefore, building-level impacts on the traditional five senses were explored. Visual perception (sight) is enabled by light. Poor lighting conditions can impact health, well-being, and personal security. The aesthetics of a space can influences emotional and social impressions. The level to which these visual impacts are tangibly assessed with functional needs (e.g. the design of displays and controls for optimal work performance, or household activities) to create visual conditions is unclear. Auditory perception (hearing) translates to building noise. Building noise has been attributed to health effects, and leading to a second order effects on financial security. Acoustic comfort is defined as minimizing intruding noise into and within buildings (Usgbc.org, 2019). Health effects due to noise in buildings as well as the second and third order effects are being cautioned (Euro.who.int, 2019). Determining a desired acoustic comfort of a space is difficult as it requires a method of measurement and design that provides a better reflection of the total noise levels of that space. The Sound Transmission Class (STC) is a measure for rating the performance of a wall system as a barrier to airborne sound transmission between closed spaces and in many open space plans. Modern electronic devices emit low frequency sounds within human hearing range that penetrate room to room and the current STC rating system does not adequately measure these frequencies. The performance of individual walls can be provided by the STC. It is not a measurement of specification used for defining the acoustic outcome of the entire functional space. A more defining approach for specifying and measuring indoor acoustic comfort is necessary. The impact of buildings on the chemical senses, gustation (taste) and olfaction (smell), are documented for the latter as indoor air quality has significant health impacts. Building-level thermal comfort is an example of the building influence on the somesthetic (touch) senses which has physiological effects. To conclude, the multi-sensory impact of the built environment on humans is a complex problem. It is argued that it is not the individual IEQ factors that impact occupant satisfaction as much as it is their collective influence (Huang et al., 2012).

Studies connecting building outcomes to its design variables through the multi-sensory impact of the built environment on humans include Kim & De Dear (2012), Barrett et al. (2013), and Barrett et al. (2015). Kim & De Dear (2012) studied the relationship between the IEQ factors in Table 6 and occupant overall satisfaction. Kim & De Dear (2012) then extrapolated Kano's model to the building context to categorize and rank the level of importance of IEQ factors on the perceived building performance. The temperature, noise level, amount of space, visual privacy, colors and textures, adjustability of furniture, and workspace cleanliness were identified as basic factors. Meaning their impact on overall satisfaction is only noticeable if they are lacking or flawed. Good performance of these factors is required as their absence can cause dissatisfaction, but presence does not heighten satisfaction. Air quality, the amount of light, visual comfort, sound privacy, ease of interaction, comfort of furnishing, building cleanliness, building maintenance, and building maintenance were identified as proportional factors meaning that the occupant's satisfaction level changes proportionally to the performance of these factors. Therefore, when they perform well, occupants are satisfied. When they perform poorly, occupants will be dissatisfied yielding a linear relationship. No IEQ factors were identified as bonus factors. These are the factors that surpass minimum expectations yielding a strong positive effect on occupant's satisfaction and no dissatisfaction in under-performance. There were no IEQ factors in the analyzed database that could potentially yield occupant delight (e.g., daylighting, external views). Office environments are perceived as purely practical with no need to excite or enthuse. A conceptual model of naturalness, stimulation and individuality acted as a vehicle to structuring and studying the full range of sensory impacts experienced by an occupant (Barrett et al., 2013), (Barrett et al., 2015). The physical factors of the built environment impacted pupil's academic progress in a primary school. Identifying the elements of design that lead to optimal, functional spaces for a function designers can help meet end user needs, and users can better adapt their spaces to their specific needs (Barrett et al., 2015). This theoretical perspective is positioned for a backward chaining perspective to connect the building outcomes (posed as value relative to the stakeholder) to building outputs.

The theoretical base for this perspective is the system-level view of the building performance. Building subsystem interactions were conceptually analyzed using systems thinking and existing sustainable building design metrics. This view connected building energy subsystems (e.g. building energy-efficiency) to their functional, social, and emotional (F-S-E) benefits and non-energy consuming building parts. The building subsystem synergies and their outcomes were connected by analyzing the pairwise interactions. This evidence-based approach led to potential insight into how the current building design process may not capture the system-level synergies that can result in sub-optimal performance. Through this work, potential points of intersection between building agents and design opportunities to improve human impacts and building performance were uncovered.

The insights from the analysis demanded a full impact model that describes and captures interactions. The interactions connect subsystems to impact-focused system-level metrics. Identification of these impacts can potentially reshape the building performance design metrics terms of its predicted impact for intentional design. Subsequently, subsystem performance metrics could normalize or link building systems in terms of their ultimate impact (i.e. building performance goals). From there, the ideal mix of building subsystems to achieve centralized metrics can be considered in building design.

Furthermore, there are a variety of counterintuitive occupant factors unrelated to the building physics that impact building energy consumption as shown through electricity consuming behavior, space heating behavior, and window-opening behavior. Tweed (2013) studied socio-technical issues with the role of energy in a retrofit experience using phenomenological analysis. From this, it was determined that carbon was not mentioned by the occupants, and energy was rarely discussed in isolation from what it enables and costs. The concepts of breakdown and affordance are metrics of the occupants' experience of a retrofitted environment. The author noted that energy and carbon items and processes are rarely a central or notable point in occupants' everyday lives. Increased storage space and a shower were more important than the energy upgrade despite the thermal shortcomings the occupants noted in the beginning. This led to the notion that occupants' energy and comfort concerns are appear and subside with other concerns in both time and space while adjusting to the space. Occupants' energy and comfort are lightly differentiated from other aspects of the home environment experience unless a problem or "breakdown" occurs which brings other concerns to the forefront. The theory of affordances can be applied to the reconfigured home landscape after a retrofit. Changing affordances after retrofit can influence how people use space which can impact energy consumption consequence.

In many building development scenarios, occupants are not involved during the design and construction phase, therefore, understanding non-occupant stakeholder gaps to achieve building energy-efficiency is important. For non-occupant stakeholders, energy-efficiency is a single performance metric and may not be the key driver of a project. However, the current building performance criteria makes it difficult for building owners to achieve greater returns on their investments while create and maintain greater building performance and long-term value (National Institute of Building Sciences, 2008). Conflicting criteria and unclear strategies to achieve optimal performance, make it difficult for building owners to exceed minimum performance standards and voluntarily pursue sustainable buildings. However, owners in the public and private sectors seek a higher level of building performance criteria in which to base the kind of optimization that will create and maintain greater building performance and long-term value (National Institute of Building Sciences, 2008).

Similarly, barriers to low-cost, energy-efficiency efforts requiring no occupant behavioral change with barriers occur at the ecosystem-level. Large initial investments for savings that accrue later, low mindshare, fragmented opportunities for various devices across numerous locations, and difficulty measuring energy-efficiency de-motivate decision-makers (Creyts et al., 2019). Homeowners are often concerned about high transaction costs, moving before recouping their investment, researching upgrades, and finding suitable contractors and have difficulty allocating money. Similar issues translate to the private sector, as many companies expect payback periods of 1-4 years for efficiency investments and depress increasing their debt and diverting money from revenue-enhancing projects (Creyts et al., 2019).

The collection of seemingly unrelated issues in the current building design paradigm were connected in view of the longitudinal value of buildings. A conceptual structure of the current paradigm shaped the ambiguity of the building performance challenge, promoted the intentional questioning and recognition of opportunities in the current building design paradigm revealing accessible flaws. One exemplary flaw was quantitatively evaluated. The systems, technical, economic, and sociological forces present in building-energy efficiency revealed the complexity in the interactions between building variables suggesting that the technical design of building energy systems should be in view of their integrated, meaningful capacity (e.g. relative to building-level human and technical standards).

Building Energy-Efficiency as a Socio-Technical Result

Many green and non-green building failures may be attributed to a disconnect between the social and technical performance between individual parts. A socio-technical approach to system development leads to systems that are more acceptable to end users and deliver better value to stakeholders (Baxter & Sommerville, 2010).

Social and technical research has presented building performance as a socio-technical phenomenon with spatiotemporal properties. These concepts have primarily been explored regarding building energy consumption as the result of the interaction between building technologies and the humans who design, use, and pay for them. Love & Cooper (2015) argued that the socio-technical nature of energy consumption needs to be researched with integrated socio-technical hypotheses directly from socio-technical theory leading to socio-technical analyses. Using standard social and technical research methods and later bringing this data together will likely result in difficulty in relating social and technical data or use of triangulation with uncertain validity. Applying socio-technical theory directly could lead to identifying new socio-technical variables of interest that cannot be derived without a systematic integrated approach. The authors noted it is crucial to capture the spatio-temporal dynamics associated with energy use and noted it is a problem is directly rooted in the initial design decisions. Considering this, Love & Cooper (2015) proposed research elements that should be included to undergo integrated socio-technical building energy research. A conceptual model should be able to theorize the anticipated social-technical interactions (e.g. how the social role of physical energy). It should be clear how the physical/technical factors of physical energy (and the corresponding technologies/materials) interact with the states of people in a social context. In the research design and analysis, social and technical data should align spatially and temporally and provide meaningful information about the human-technology interaction.

The number of social and technical influences on a single building performance metric (e.g. building energy-efficiency) is displayed in Figure C7. The developer and architect make decisions about the building that impact the owner and the occupant economically or environmentally over time. The results of these decisions also impact the utility provider. The building surrounding occupants is created by several electrical, mechanical, and water systems as well as structural elements. The developer and architect are the primary decision-makers in the selection of these systems in the developmental stages, that responsibility shifts to the property owner(s) after construction. The performance of these systems is dependent on external factors such as the available fuels, the outdoor climate, and the building orientation. The available utility sources are dependent on the providers and the developer/architect as they select the building location. The outdoor climate is dependent on the building location and its effects on building are dependent on the building orientation and the built environment systems selected by the developer/architect. The electrical, mechanical, and water systems influence each other as well as the structural elements. Their collective performance cultivates the built environment and defines the building performance. Occupants receive environmental information in the presence of external stressors, social factors, physical, and internal stressors (e.g. fatigue and cyclical changes) effecting their internal cognitive state. The occupant may choose to interact with the building, and depending on the building system, this may send a response to the utility provider. Second, the complexity of the building performance ecosystem is confirmed in Figure 12.

These diagrams highlight opportunities to expand the current paradigm from building energy-efficiency-focused to impact-focused metrics to achieve building-energy efficiency and other performance metrics, and to identify comprehensive, system-level interrelationships between building parts (including non-energy consuming systems). Using a systems view, there is an opportunity to understand the scope of building impacts on occupants, and if there is any headroom to improve life quality (or meet occupant needs) through the inclusion of non-physical factors. Potentially, this could be achieved by shifting building design focus from component-level physical metrics to holistic impacts or outcomes.

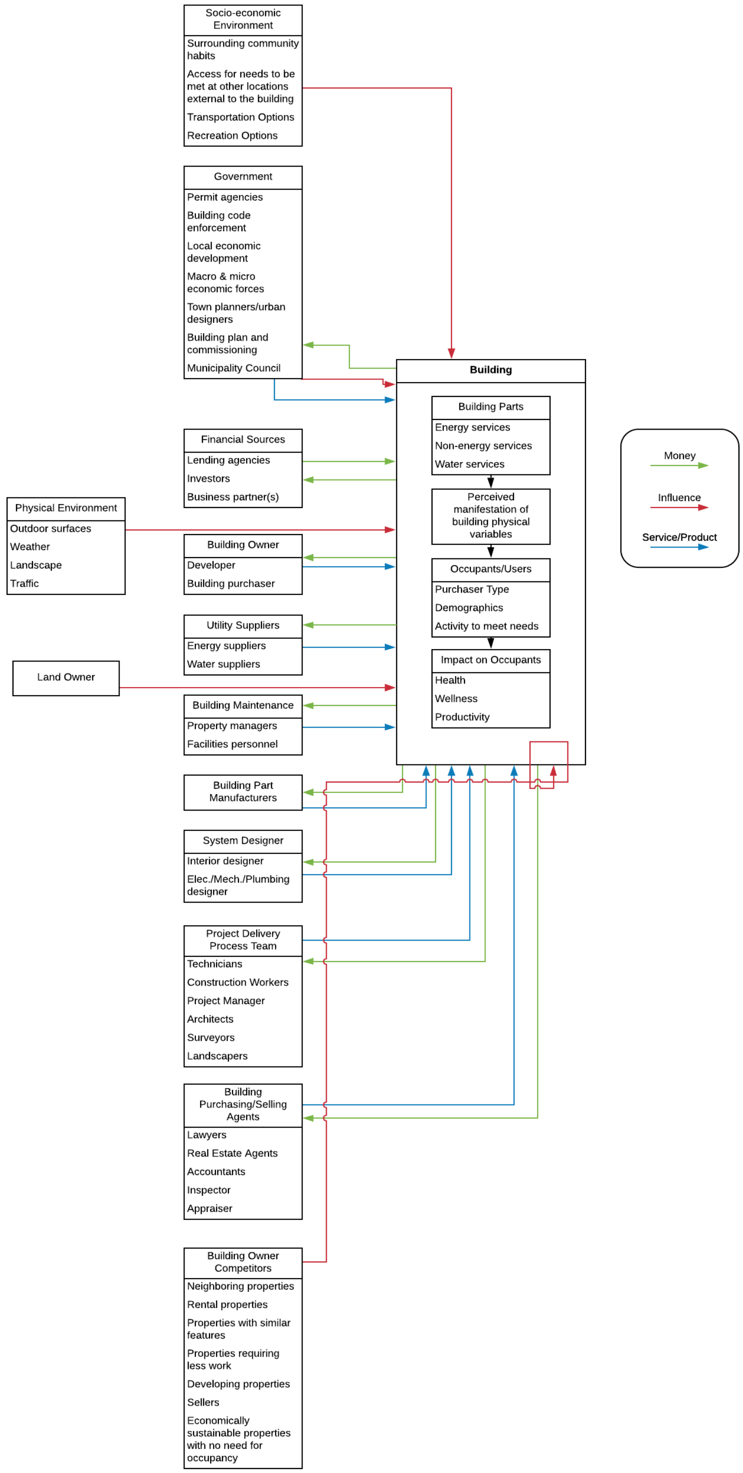

Figure C5: Influences on building performance

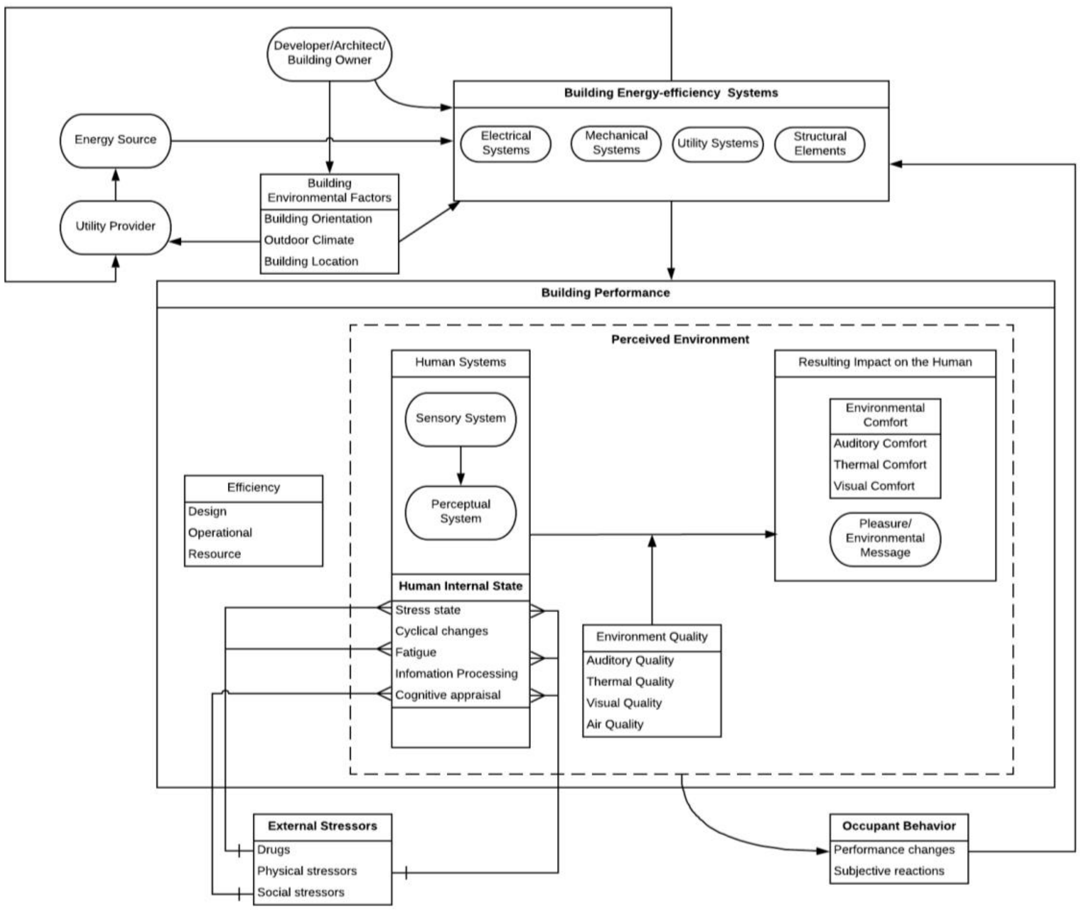

Figure C6: Socio-technical relationships in achieving building energy-efficiency

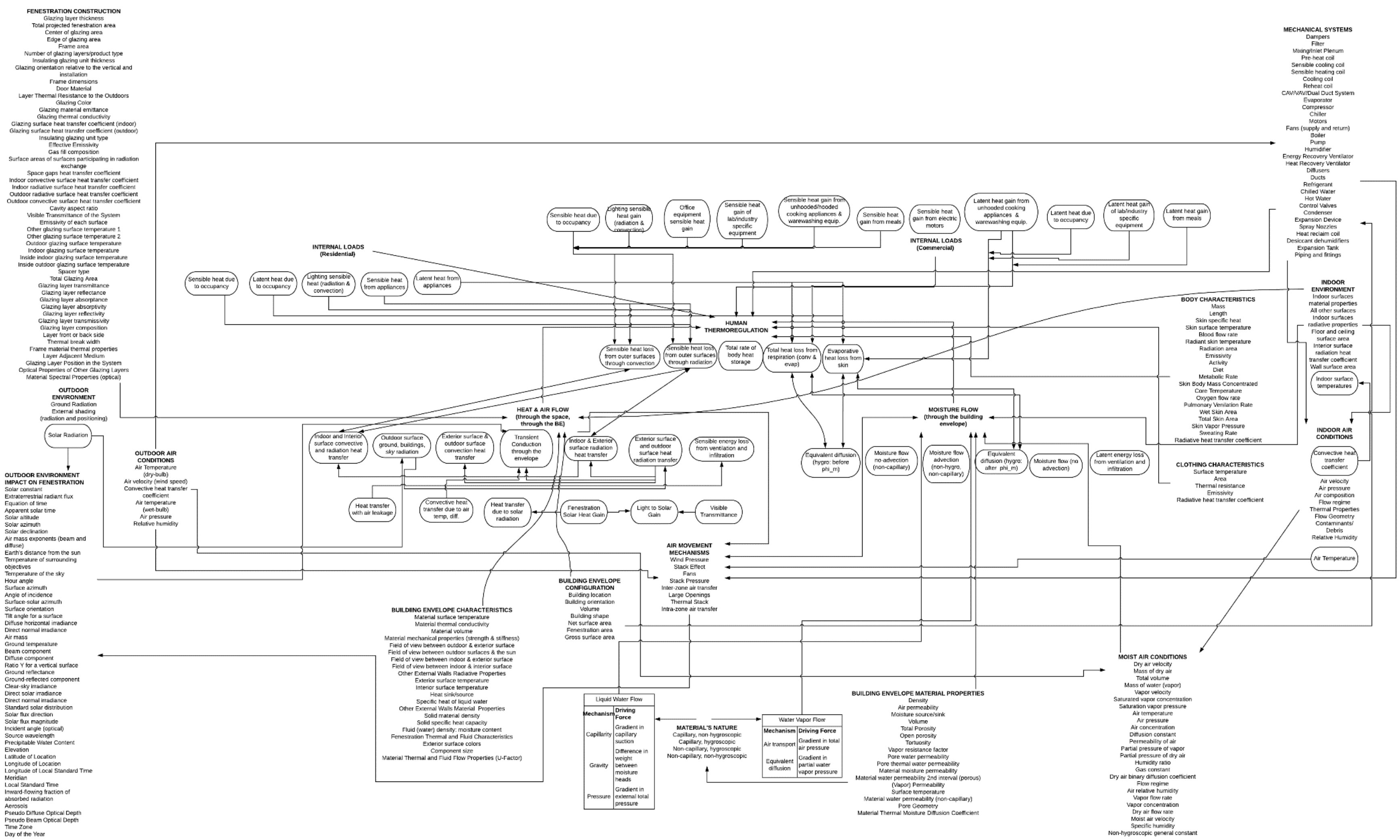

Figure C7: Conceptual reconstruction of physical building energy interactions

Expanding idea spaces by connecting generalized first principles

New ideas to achieve a value-centered building design paradigm may be generated by learning from new schools of thought, examining morphological combinations, and noticing other trends perpetuated by the longitudinal disconnect of building value creation. Targeted innovation for more effective buildings may be learned from health care and value engineering.

New ideas to explore solutions to the first principle problem of the disconnect in the longitudinal building value creation were generated by reviewing information around performance, effectiveness, and connecting design to value. As a result, a new perspective which captured the socio-technical, spatio-temporal nature of building performance dimensions was developed using implementation science. Implementation science provided a construct which captured the flaw in the current paradigm, and the systems, technical, economic, socio, and psychological forces which yield building energy-efficiency challenges. Also, a systems view of building performance was explored using systems thinking to generate a holistic picture required for sustainable buildings. This effort supports the potential benefit of framing building energy systems as sociotechnical systems to yield large-scale transformation in addressing energy demand challenges (Sorrell, 2015).

Supporting host ecosystems

The building performance knowledge management scheme and cost-benefit analysis were developed to address the needs of host ecosystems to potential value-centered building design paradigm. The building performance knowledge management scheme may aid with mapping ecosystem elements predicting the potential reach of a solution. Also, it may allow for performance models to capture the end-user decision-making environment. The cost-benefit model enables quantifiable reconfiguration of ecosystem nodes, links, interactions, and capturing ripple of effects. New business models presented are a map of ecosystem elements, and a reconfiguration of ecosystem nodes and links. Collectively, these tools may aid in the development and assessment of impact-focused solutions which intentionally address the needs and values of affected populations, comprehensively connects the various factors to impactful performance dimensions.

Rethinking performance and connection to early impact contexts

The dimensions of effective building performance may help express dimensions of performance across many different contexts, and expose possible performance dimension combinations. New business models have the potential to enable pursuit of new performance dimensions and connect solutions to early impact contexts. The joint use of the tools presented may aid in mapping counter intuitive tradeoff combinations, measuring performance headroom, and connecting solutions to contexts including those in which tradeoffs may be beneficial.

APPENDIX D. PURSUING A PATH TO REIMAGINE BUILDING PERFORMANCE

The systems and longitudinal views of building performance, the knowledge management scheme of building performance, economic model, and innovative business model approaches may aid practitioners, developers, and researchers to intentionally pursue building solutions for equitable, sustainable residences.

Table D1: Behaviors to Pursue Enabling Innovations

Behavior	Definition	Delineating Actions	Actionable Principles
Communicate: Tell stories that paint a vision	Communicate persuasively to build buy-in for ideas	• Describing pitch ideas and stories to communicate	• Identify audience and key influences • Structure story according to goal and circumstance • Create contrasts and turning points to highlight key insights • Balance logic, emotions, and knowledge • Integrate story with a resolution
Communicate: Create win-win partnerships	Building relationships with ecosystem stakeholders that can influence the success of an idea	• List stakeholders from which buy-in is required • Create strategies to partner with such stakeholders	• Identify ecosystem areas in which partnerships would be beneficial • Identify ecosystem players and their desired outcomes in relevant areas • Create a network perspective of relevant stakeholders • Contrast desired outcomes of relevant stakeholders in matrices • Identify possibilities for win-win partnerships • Create a business case for desired partners & seek to build relationships
Communicate: Convey counterintuitive insights	Convey ideas that deviate from those typically encountered in a given context in tailored/perceptive ways	• Create experiences that convey aspects of an idea • Describe ways to communicate non-traditional insights	• Identify knowledge to be organized and emotions to be managed in audiences • Identify conflicts and tensions between the status quo and insights to be conveyed • Select a delivery vehicle • Facilitate a process to help stakeholders unearth their hidden assumptions

Table D1 continued

Communicate: Drive habit conversion	Influence/nudge decisions through the presentation of choices	• Describe stakeholder habits to change • Implement habit conversion strategies	• Map out the habits implicit in a given paradigm • Decompose habits into cues, routines, and rewards • Assess possibilities for causal linkages between cues, routines and rewards • Identify target routines, experiment with rewards and isolate possible cues • Nudge people through the presentation of choices
Implement: Experiment for smart failure	Pursue first-hand iterative learning via active experimentation	• Conduct experiments to uncover the path to success • Manage the uncertainty of an idea through planned experimentation	• Run tests in series based on prioritization criteria • Re-adjust experimentation efforts as needed • Explicitly document learning insights after each testing stage • Re-prioritize and re-direct experimentation efforts after each learning insight
Implement: Select paths to earn and learn	Choose between paths to pursue based on learning potential and potential to achieve/earn impact	• Select among implementation alternatives • Choose paths that are likely to lead to both impact and learning	• Prioritize paths according to innovation enabling goal • Assess learning potential across possible paths • Assess “earning” potential across possible paths • Select paths that generate trial, learning, and “earnings” for continued development

Table D1 continued

Implement: Leverage unintended consequences	Capitalize on unexpected occurrences that highlight new paths, goals or ideas	• Identify unexpected opportunities and barriers in the pursuit of an idea • Analyze the consequences of such unanticipated opportunities and barriers	• Examine the results of smart failure experiments • Uncover second and third order effects from the results of experiments • Distil learning insights from contextual influences • Search for opportunities to leverage learning in other tests or contexts • Embed unintended findings in the pursuit of subsequent learning goals
Implement: Differentiate when to stop or persist		1.	• Assess upside potential relative to halting efforts • Persist when obstacles are encountered and find lessons in setbacks • Learn from feedback and criticism • Acknowledge the difficulty and resistance to paradigm and culture change • Assess the need for additional cascading sponsorship, talent, or resources
Implement: Adapt based on learning		2.	• Synthesize learning insights from experiments to date • Assess whether experimentation efforts should be continued, re-directed, halted, or re-designed • Set periodic checkpoints to compare upside potential with continuation cost at the portfolio level • Allow the path to success to unfold from the results of experiments and learning opportunities

Table D1 continued

Define Path: Create learning experiments	Create a set of experiments that can be used to learn more about an idea and convert its assumptions into knowledge	• List possible metrics that can be used to track the success of an idea	• Employ visions of impact pathways and learning metrics • Assess the need for targeted or comprehensive experiments for each key assumption and metric • Devise a series of low-intensity tests that minimize the failure of impact • Define parameters that will determine whether a test is positive, inconclusive, or negative • Outline assumptions, metrics, hypotheses, resources and parameters for each experiment
Define Path: Identify learning metrics and assumptions	Link a set of assumptions inherent in an idea to a set of metrics that can be used to track the conversion of assumptions into knowledge	• List assumption inherent to an idea • Identify metrics that can be used to track the success of an idea	• Decompose and an implementation path into learning gaps and failure mechanisms • Ensure assumption list includes technical, systemic, economic, and socio-emotional • Diverge, structure and asses the relationship of assumptions to candidate learning metrics • Define key metrics that could be used to test failure mechanisms • Assess the severity of assumptions and failure mechanisms
Define Path: Envision multiple pathways	Mapping possible pathways to idea success given the uncertainty that is inherent in ideas with enabling potential	• Identify many possible paths to success • List potential pathways of an idea	• Diverge, structure, and converge possible paths for each concept and context of pursuit • Evaluate each path on a set of predetermined metrics using multiple lenses • Prioritize paths according to end goal, metrics, and position in impact curve • Create and balance a portfolio of implementation possibilities

APPENDIX E. HOW THE ETF INFORMED THE RESEARCH STRATEGY

To reimagine building performance, and the research question and methodology initial requirements were set. Application of the ETF design behaviors at the research onset yielded the insight to explore and define the longitudinal value of buildings as a potential research path. The research question was posed in a way to allow for knowledge production constrained to the building context, yet applicable to other contexts, allowing for the opportunity to solve incremental building performance issues in other spaces (and vice versa). Not only do the research methodologies stand to address ecosystem-level problems due to the research question formulation, but also the initial research methodology are requirements were set to address key stakeholders in the building design and development stages, mitigate researcher bias, and balance stakeholder needs. The solution space was mapped by the building impact cascade and the opportunity space created from emerging trends that can enable the new building value-centered paradigm. Conversely, solving the re-shaped problem is the focus of the work herein. First, a strategy to move from the problem space to the solution space is developed using foundational problem-solving approaches, the remaining ETF behaviors, and the previously described known problem information.

The insight to explore and capture the longitudinal value of buildings was revealed as a research path to reimagine building performance by entrenching research activities in building impact-focused design behaviors (e.g. employing the first stage of the ETF). Foremost, the research question was posed in a way to allow for knowledge production constrained to the building context, yet applicable to other contexts, allowing for the opportunity to solve incremental building performance issues in other spaces (and vice versa). Not only do the research methodologies stand to address ecosystem-level problems due to the research question formulation, selected methods were aimed to address key stakeholders in the building design and development stages, mitigate researcher bias, and balance stakeholder needs. The solution space was mapped by the building impact cascade and the opportunity space created from emerging trends that can enable the new building value-centered paradigm.

The ETF suggests that this behavior can be achieved by proactively recognizing all possible influences in a given situation, creating empathy-based mental models, and observing the change in forces across different circumstances; all of which informed the current research question, working hypothesis, research question and subsequent research streams. The first two illustrative actions were taken – noticing the forces at play and creating empathy-based mental models – but observation of the forces under diverse circumstances was employed in the selected future research methodologies directly. The forces at play in the building energy-efficiency challenge were explored by gathering information about: the building-level perspective of component physical (energy) interactions and technological challenges, the drivers and inhibitors of building energy-efficiency; eluding to the social and technical nature of building energy-efficiency challenge. An empathy-based perspective was informed by gathering information about direct stakeholder challenges. Consequently, the problem was reframed to its current form by theorizing the influences on building performance, and socio-technical relationships in building energy-efficiency.

Recognition of the flaws in current building design paradigm and the systems, technical, economic, and sociological forces involved in building performance discloses the reinforced disconnect between design outputs and outcomes – the research problem - in the current design philosophy. This problem is grounded (and exacerbated in the current design paradigm) in the complexity of the building performance ecosystem. The information in Appendices B and C informed the conceptual socio-technical reconstructions of building energy influences and overall building performance influences support a spatio-temporal perspective, and ground the problem in way where the variety of building variables and outcomes are a benefit. These perspectives yielded the question, "how can we improve building (system and subsystem) design to achieve impact-based performance metrics?" The answers to this question should enable direct stakeholders to receive the maximum building benefits and distribute the costs longitudinally. Therefore, the research question and streams were informed and developed to investigate solutions to the building performance challenge.

The initial physical perspective of building energy-efficiency led to the research question, and preceding hypotheses. Emergent behavior from this complexity affirms the requirement to design physical variables in view of their integrated, meaningful capacity. Recognition of these forces also demanded the need to expand the research problem from building energy-efficiency challenge to the building performance challenge. It also revealed the need to develop a spatio-temporal strategy to enable building performance; one that supports the development of solutions that intentionally captures the diversity of building variables and outcomes. Herein, the ETF was employed to color and redefine the building performance challenge by framing the flaws in the current paradigm, and providing a new lens that captures the underlying technical, economic, systems, sociological, and psychological issues associated with the current paradigm.

Elemental problem-solving approaches serve as a guide to develop a strategy to develop the solution space. Trial and error, forward chaining, are backward chaining are three primary problem-solving approach concepts in psychology as shown in Figure E1 (Proctor et al., 2008, p. 292). The current research in building performance employs a forward chaining approach by working the problem from the initial (current) state, evaluating all possible problem-solving options, selecting and implementing an action, and learning from the feedback of the action. This problem-solving approach is often employed in game theory and artificial intelligence (Hollis, 1991) (Noldeke & Samuelson, 2010) (Qu & Doshi, 2017) (Leonidas, 2009), and starts with the reviewing the available data then applying inference rules to extract more data until a goal is reached. A trial-and-error approach is the experimentation of possible problem-solving options until one is successful. This research will employ a backward chaining approach; beginning with an understanding of the goal state and constructing a solution path to the initial (current) state yielding a sequence of optimal actions to achieve the goal state from the current state. The backward chaining approach, also known as backward induction, is a vehicle to structure the subsequent research streams for the research problem. As such, the research streams are the development of a goal state, and a set of actions to towards a new initial state. The research strategy continues to be guided by the ETF design patterns and behaviors to yield impact-focused research activities.

The goal state is an optimized longitudinal distribution of the building benefits and costs for its stakeholders. In order to achieve this: a systems-view of the building, a comprehensive view of the building impacts on its beneficiaries – or building efficacy, and a means to optimize those impacts must be understood; leading to the shaped solution paths (e.g., the two subsequent research streams of design and business model innovation). The first half of Research Stream 1 has been accomplished and is described in Chapter 5; the mixed-method approach to study building efficacy, and the application of business model innovation as a vehicle to optimize the building value are described in Chapter 6.

The systems view of the building initiates building design innovation by broadening idea spaces and connecting generalized first principles; achieved by the illustration of three ETF behaviors – interrelating new schools of thought, exploring morphological combinations, and connecting core ideas to diverse problem and solution spaces. Understanding the system-level interactions in between building energy systems and non-energy consuming building systems, and the occupant, highlighted counterintuitive synergies not explicitly captured in current building design performance metrics, exposed cause-effect patterns and features of the problem and solution space across contexts. This systems-view provided a transductional view of building energy systems; connecting the physical, functional, social, and emotional impacts of component interactions, and confirming the building design efficacy gap.

The second half of Research Stream 1 and Research Stream 2 further shape solution paths by employing ETF design patterns to address the host ecosystems, and rethink performance and its connections to early impacts contexts; the exact ETF design behaviors employed was discussed after execution of the research. The second half of Research Stream 1, in pursuit of design innovation, is the study of building efficacy. This work entails gaining a concrete view of stakeholder building-related engagements - the motivation of the engagement, the immediate result of the engagement (e.g. efficacy), the value of the engagements, and potential efficacy indicators – addressing the building efficacy gap, providing insight into the relevant metrics of buildings over time, accounting for the physical and non-physical factors that influence building performance, and encouraging the creation of innovative building solutions that deliver on socio-technical and spatio-temporal dimensions which capture the complexity of the variables and outcomes at the building performance nexus. The building value deduced from Research Stream 1 guides the business model innovation in Research Stream 2. This research examines an economically feasible socio-temporal strategy to create, deliver, and capture the value of buildings and the creation of a model to assess when and how to develop sustainable buildings. These methods were also selected to overcome the typical design science limitations and illustrate the following design behaviors listed in Table E2.

In conclusion, this research path will yield recommendations to change current design practices to mitigate their human-related issues and encourage the adoption of sustainable buildings. The interpretation and insights from the research can be used to create strategies to pursue solutions in alignment with ETF behaviors.

Second, the technical, economic, systems, sociological, and psychological issues were informed by observing building-related problems across diverse circumstances, proactively perceiving all possible influences on building performance, and the use of empathy-based mental models.

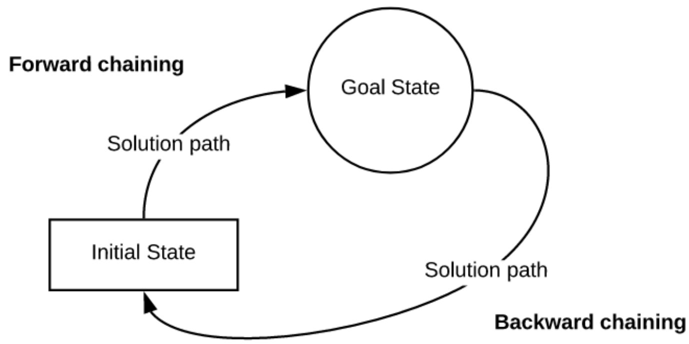

Figure E1: Problem-solving approaches

Table E1: Summary of learnings to address during problem-solving

Design science limitations
Provide a systems view of the problem
Consider ecosystem factors
Not focus on a specific feature/life phase
Provide insight into in-situ use (i.e. not exclusive employment of anthropometric data or in-lab testing)
Remove the context of the problem for usable design goals
Ensure solutions are not shaped by the agenda and resource constraints of the most powerful players
Stipulate rigorous attention to the designer's positionality
Address rapidly changing or high uncertainty areas
Acknowledge inherent organizational risk-averse culture
Propel egalitarian, high-performance teams

Table E2: Foundational concepts for building performance framework

Foundational Concepts	Description and Relevance	Tenets	Building Performance Adaptation
Design Science (general)	• A holistic and systematic form of designing that has been viewed as a problem-solving approach or a planning tool with a specific path • Problems in the ecosystem should be considered in the holistic view of the system, and problems in the use and implementation of the system should be among those prevented • Bridges the gap between practice and academia by developing actionable knowledge that is grounded in evidence (Holloway et al., 2016) • Suitable to address the socio-technical-economic, and complex nature of human-building interaction	Information and communication technology systems (Vaishnavi & Kuechler, 2015), Organization and management (Bate, 2007) (Holloway et al., 2016) Healthcare business intelligent systems (Kao et al., 2016), Tourism design (Fesenmaier, & Xiang, 2017) Information systems (Hevner et al, 2004) Performance-oriented workplace e-learning system (Wang et al., 2011)	• A systematic, holistic approach to capturing a view of building performance considering the socio-technical and spatio-temporal elements
Enabling Thinking Framework (design science)	An organized approach to an end-to-end design process model tied to innovation outcomes (Solis & Sinfield, 2018). This design process is comprised of stage-specific design behaviors and a set of core behaviors focused on achieving impactful innovations.	Design and innovation research	• Envision a path for building innovation • Reframe the lens of building performance

Table E2 continued

Backward Chaining (psychology)	• An elemental problem-solving approach that begins with understanding the goal state (e.g. effective buildings) and constructing a solution path to the initial (current) state yielding a sequence of optimal actions to achieve the goal state from the current state • Structures designing for a vision	Game theory and artificial intelligence (Hollis, 1991) (Noldeke & Samuelson, 2010) (Qu & Doshi, 2017) (Leonidas, 2009)	• Buildings research and practices can strategically manage resources and take new actions to achieve new outcomes, value, and innovative solutions. • Can guide design practice changes and strategy development for effective solutions from the ideal building performance outlook to the current problem space utilizing the presented framework.
Mechanics-Dynamics-Aesthetics (MDA) Framework	• Formal approach to understanding game consumption • Improves games by bridging the gap between game design and development, criticism, and research (Hunicke et al., 2004) • Aids in analyzing the end result to refine implementation and vice versa (Hunicke, et al., 2004)	Game design (Hunicke et al., 2004)	• Offers a synonymous context for a mental model to structure the ambiguity in the current building design paradigm • Logic applied to organize the problem and solution spaces of current building design challenges

Table E2 continued

Implementation Science	• The study of methods and strategies to promote the uptake of interventions that have proven effective into routine practice, with the aim of improving population health (https://www.gacd.org/research/implementation-science) • Implementation theory is a good start to shift an industry, organization, or program paradigm to focus on outcomes rather than activities, and aid in the evaluation of existing programs. • Logic models are often used as planning and evaluation tools for a project, program or intervention	Healthcare Project management	• Delineates a longitudinal, socio-technical view of the building system in terms of the stages that yield system performance through a building value logic model enabling the design for and evaluation of outcomes and values
Performance Theory	• The work-related behaviors of individual employees, their contribution to the organization • Studies and measures individual effectiveness toward system (e.g. organizational) goals	Organizational Psychology/Employment system (Sonnentag & Frese, 2005) Organizational Learning (Elger, 2007)	• Offers a synonymous context to characterize the systemic elements of socio-technical performance, potential dimensions of building effectiveness, and frame to study whole-building performance in view of the constraints and needs of building ecosystem
The Donabedian Model	• The Donabedian model is segmented into three constructs – structural, process, and outcomes - assuming if structural variables lead to a process, and that process leads to outcomes; then the structural and outcomes are causally related. • The Donabedian model is a classification system to assess and compare the quality of health care organizations.	Healthcare	• Provides a conceptual framework to measure building quality • Offers a synonymous context to expand the building paradigm from outputs to outcomes as the new paradigm demands new, outcome-focused metrics in addition to the current conventional metrics to create a robust yet balanced set of metrics

APPENDIX F. QUALITATIVE STUDY PROTOCOLS

Purpose stemmed search words and synonyms:

Purpose/Generic:

"acqui","gain","obtain","attain","achiev","access","reach","procur","develop","decre","claim",

"find","found","seek","sought","need","transfer","want","get","foster","enabl","drive","grow", "muster","generat","engender","cultivat","increas","enhanc","stimuulat", "leverag","mainten",

"appl","buy","bought","produc","induc","solicit","fulfill","confer","facilitat","search","get",

"support","propagat","appropriat","learn","earn","exchang","incentiv","influenc","maintain","go al",

"purpos","objectiv","goal","accomplish","inten","aspir","motiv","encourag","spur","creat","own ",

"reason","vision","misison","plan","lead","meausre","asses","aim","desir","chang","reduc","desi r"

"avail","convenien","hospita","eas","agree","ready","hand","manag","control","protect","susten" ,"sav",

"discov","close","impact","connec","effect","profit","afford","worth","cost","value","practic","pr agma",

"price","rate","adv","proxim","respons","shar","gain","benefi","renum","recoup","rebat","incom e","rent", "viab","financ","sal","expen","deal","bargain","reduc","belie","aesthe","beaut","creat","invent"," featur",

"pleas","art","design","attract","innovat","struct","favor","pref","agree","relat","sustain","resil",

"restor","resist","energ","effic","renew","dura","long","surviv","adapt","flex","stren","stron","att ri",

"heal","well","being","saf","protect","comfort","liv","secur","priv","prod","green","just","bio","e co",

"histor","skill","soci","resourc","asset","valu","capital","tech","need","quali","gen","equit","fair" ,

"suffi","perform","lik","good","outcome","lab","preserv","strateg","return","arch","sel","last","n ear"

Context stemmed search words and synonyms

"context","feature","background","situat","condition","variable","variabilit","depend","constrain ",

"setting","climate","backdrop","surroud","scene","environment","factor","dimension","uncertain ",

"area","field","focus","locus","attribut","domain","circumstan","connect","arena","limit","scal"

Context/Framework:

"climat","communit","cultur","econom","market","industr","environment","infrastructur",
"proj","prop","people","funct","govern","polic","polit","regulat","organiz","organis",
"risk"," soci","commerc","law",
"human","soci","build","operat","institut","legal","struc"

Resource Elements: "resourc","asset","valu","capital","tech","need","quali"

Relationship Elements: "relation","account","commit","commun","conflict","tens","compromi","align","mutual","exchang",

"agree","deci","trust","transparen","role","responsib","flex","share","manag","coordinat"

Hypothesis-driven Search Inputs

BUILDING TYPE: “smart* ho*” OR "resilien* ho*” OR "carbon ho*” OR "intelligent ho*” OR “resident* building*” OR “home*” OR “housing*” OR “resident* real estate*” OR “residential propert*” OR "residence*" OR "residential setting*" OR "dwelling*” OR "sustain* hous*” OR “institutional group I” OR “residential group R”

FACTOR SYNONYMS: “condition*” OR “variable*” OR “factor*” OR “characteristic*” OR “pattern*”

STAKEHOLDER: “individual*” OR “group*” OR “stakeholder*” OR “beneficiar*” OR “person*” OR “people” OR “occupant*” OR “owner*” OR “investor*” OR “resident*” OR “famil*” OR “household*”

“marginal* group” OR “marginal* communit*” OR “communit*” OR “firm*” OR “organization*” OR “societ*”

STAKEHOLDER CHARACTERISTICS: “race” OR “gender” OR “genetic” OR “personality” OR “demographic” OR “income” OR “work” OR “health status” OR “employment” OR “age” OR “marital status” OR “education”

BUILDING OUTCOMES OR IMPACT DIMENSIONS: “benefit*” OR “cost*” OR “access*” OR “afford*” OR “equit*” OR “dispar*” OR "energy-efficien*" OR "energy consum*" OR “outcome*” OR “impact*” OR “value*” OR “income*” OR “work activit*” OR “efficien*” OR “value network*” OR “productiv*” OR “busines*” OR “financial resource*” OR “economic growth” OR “economic*” OR “environment*” OR “livab*” OR “hospitab*” OR “control*” OR “suitab*” OR “securit*” OR “mobil*” OR “spa*” OR “facilit*” OR “connect*” OR “group interact*” OR “locat*” OR “infrastruct*” OR “resource availab*” OR “climate change” OR “physic* health” OR “soci* health” OR “emotion* health” OR “well-being” OR “life satisfaction” OR “social state*” OR “physical state*” OR “relationship*” OR “emotional state*” OR ”communit* health” OR “social network*” OR “sense of belong*” OR “percept*” OR “experien*” OR “health*” OR “public health” OR “health pattern*” OR “soci*-emotional health” OR “cultur*” OR “lifestyle*” OR “habit*” OR “educat*” OR “knowledge*” OR “skill*” OR “abilit*” OR “learn*” OR “function*” OR “emotion*” OR “soci*” OR “sense of identit*” OR “expressions of individual*” OR “belie*” OR “organization* structure*” OR “organization* interaction*” OR “collective knowledge*” OR “shared belie*” OR “polic*” OR “government*” OR “demographic*” OR “bod* of knowledge*” OR “culture* norm*”

<u>EXCLUSIONS</u> - NOT "wildlife" OR "animal*" OR "agricultur*"

EBSCO Search inputs

Academic Search Premier, AgeLine, Applied Science & Technology Full Text (H.W. Wilson), EBSCO Management Collection, EconLit, Education Full Text (H.W. Wilson), Ergonomics Abstracts, Family & Society Studies Worldwide, GreenFILE, Home Improvement Reference Center, Library, Information Science & Technology Abstracts, MasterFILE Premier, Military & Government Collection, APA PsycInfo, Race Relations Abstracts, Shock & Vibration Digest, Social Sciences Full Text (H.W. Wilson), Business Source Complete, Entrepreneurial Studies Source, MasterFILE Complete, Academic Search Complete, Psychology and Behavioral Sciences Collection

TI Title
“smart* ho*” OR "resilien* ho*” OR "carbon ho*” OR "intelligent ho*” OR “resident* building*” OR “housing*” OR “resident* real estate*” OR “residential propert*” OR "residence*" OR "residential setting*" OR "sustain* hous*” OR “institutional group I” OR “residential group R”

TI TITLE
“condition*” OR “variable*” OR “factor*” OR “characteristic*” OR “pattern*”

AB ABSTRACT

“individual*” OR “group*” OR “stakeholder*” OR “beneficiar*” OR “person*” OR “people” OR “occupant*” OR “owner*” OR “investor*” OR “resident*” OR “famil*” OR “household*”

AB ABSTRACT

“benefit*” OR “cost*” OR “access*” OR “afford*” OR “equit*” OR “dispar*” OR "energy-efficien*" OR "energy consum*" OR “outcome*” OR “impact*” OR “value*” OR “income*” OR “work activit*” OR “efficien*” OR “value network*” OR “productiv*” OR “busines*” OR “financial resource*” OR “economic growth” OR “economic*” OR “environment*” OR “livab*” OR “hospitab*” OR “control*” OR “suitab*” OR “securit*” OR “mobil*” OR “spa*” OR “facilit*” OR “connect*” OR “group interact*” OR “locat*” OR “infrastruct*” OR “resource availab*” OR “climate change” OR “physic* health” OR “soci* health” OR “emotion* health” OR “well-being” OR “life satisfaction” OR “social state*” OR “physical state*” OR “relationship*” OR “emotional state*” OR ”communit* health” OR “social network*” OR “sense of belong*” OR “percept*” OR “experien*” OR “health*” OR “public health” OR “health pattern*” OR “soci*-emotional health” OR “cultur*” OR “lifestyle*” OR “habit*” OR “educat*” OR “knowledge*” OR “skill*” OR “abilit*” OR “learn*” OR “function*” OR “emotion*” OR “soci*” OR “sense of identit*” OR “expressions of individual*” OR “belie*” OR “organization* structure*” OR “organization* interaction*” OR “collective knowledge*” OR “shared belie*” OR “polic*” OR “government*” OR “demographic*” OR “bod* of knowledge*” OR “culture* norm*”

TX ALL TEXT

NOT "wildlife" OR "animal*" OR "agricultur*"

APPENDIX G. CBA EQUATIONS

$$Annual\ benefit\ of\ indoor\ comfort\ conditions = WTP * number\ of\ nights\ in\ 1\ year \quad (4)$$

$$Annual\ cost\ of\ thermal\ discomfort = \frac{household\ annual\ salary * number\ of\ work\ time\ lost}{number\ of\ work\ hours\ in\ a\ year} * productivity\ loss \quad (5)$$

$$Annual\ cost\ of\ sleep\ quality = \frac{annual\ societal\ cost\ of\ sleep}{number\ of\ US\ households}$$

$$Annual\ financial\ energy\ savings\ benefit\ of\ energy\ conservation = price\ of\ energy(\frac{\$}{kWh}) * annual\ energy\ consumption\ (kWh) * percentage\ of\ potential\ savings\ (\%)$$

$$Annual\ financial\ energy\ savings\ benefit\ of\ energy\ management\ system = price\ of\ energy(\frac{\$}{kWh}) * annual\ energy\ consumption\ (kWh) * potential\ savings\ (\%)$$

$$Annual\ financial\ energy\ savings\ benefit\ of\ energy\ demand\ reduction\ programs = price\ of\ energy(\frac{\$}{kWh}) * annual\ energy\ consumption\ (kWh) * percentage\ of\ potential\ savings$$

$$Annual\ energy\ savings\ benefit\ of\ energy\ demand\ reduction\ programs = peak\ load\ reduction\ (\%) * annual\ energy\ consumption\ (kWh) * benefit - cost\ ratio\ (\%)$$

$$Annual\ cost\ of\ unaffordable\ housing = number\ of\ workers\ in\ the\ household * cost\ in\ additional\ wages\ per\ worker$$

$$Annual\ benefit\ of\ short-term\ behavioral\ change$$
$$= percent\ reduction * direct\ household\ emissions\ (\frac{carbon}{year})$$

$$Annual\ benefit\ of\ sustainable\ development$$
$$= \sum annual\ benefits\ \left(\frac{\$}{ft^2}\right) * house\ size\ (ft^2)$$

$$Annual\ health\ effect\ reduction\ benefits\ (from\ noise\ abatement\ )$$
$$= \sum annual\ household\ health\ care\ savings\ (\%)$$
$$* household\ health\ care\ costs (\$)$$

$$Annual\ public\ cost\ of\ environmental\ health = \frac{total\ societal\ cost}{number\ of\ US\ households}$$

- As the value is low it is used as a household estimate to assume the child in the household develops pediatric asthma

$$Annual\ cost\ of\ pediatric\ asthma$$
$$= \frac{Total\ environmental\ health\ cost\ of\ pediatric\ asthma}{number\ of\ US\ household}$$

- Assume a hurricane occurs

$$Annual\ cost\ of\ climate-change\ events\ on\ health$$
$$= \frac{Normalized\ cost\ per\ 1000\ people\ environmental\ health\ cost\ of event}{1000}$$
$$* number\ of\ people\ in\ the\ household$$

$$Household\ health\ care\ expenditure\ reduction\ from\ improved\ housing\ conditions$$
$$= \ reduction\ per\ member\ per\ month * number\ of\ months\ in\ a\ year$$

$$Peak\ demand\ benefit$$
$$= peak\ demand\ price * household\ demand * demand\ cost-benefit\ ratio$$

$$Total\ potential\ income = total\ rental\ income + total\ other\ income$$

$$Effective\ gross\ revenue\ (EGR) = Total\ potential\ income - rental\ revenue\ losses$$

$$Net\ operating\ income\ (NOI) = total\ operating\ expenses - EGR$$

$$Cash\ flow\ from\ operations = CapEx - NOI$$

APPENDIX H. PHASE 1 QUALITATIVE STUDY TOPIC MODELLING RESULTS

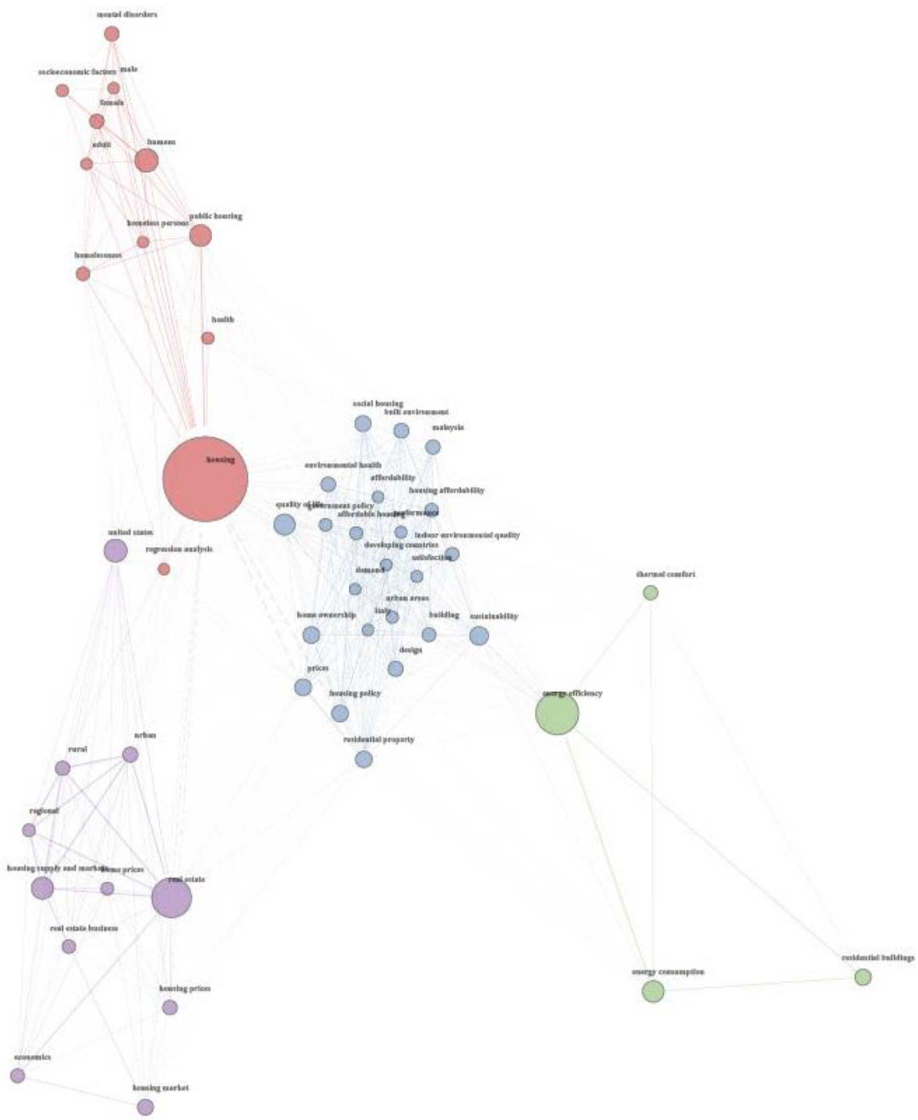

Figure H1: Insert top 50 co-occurring diagram

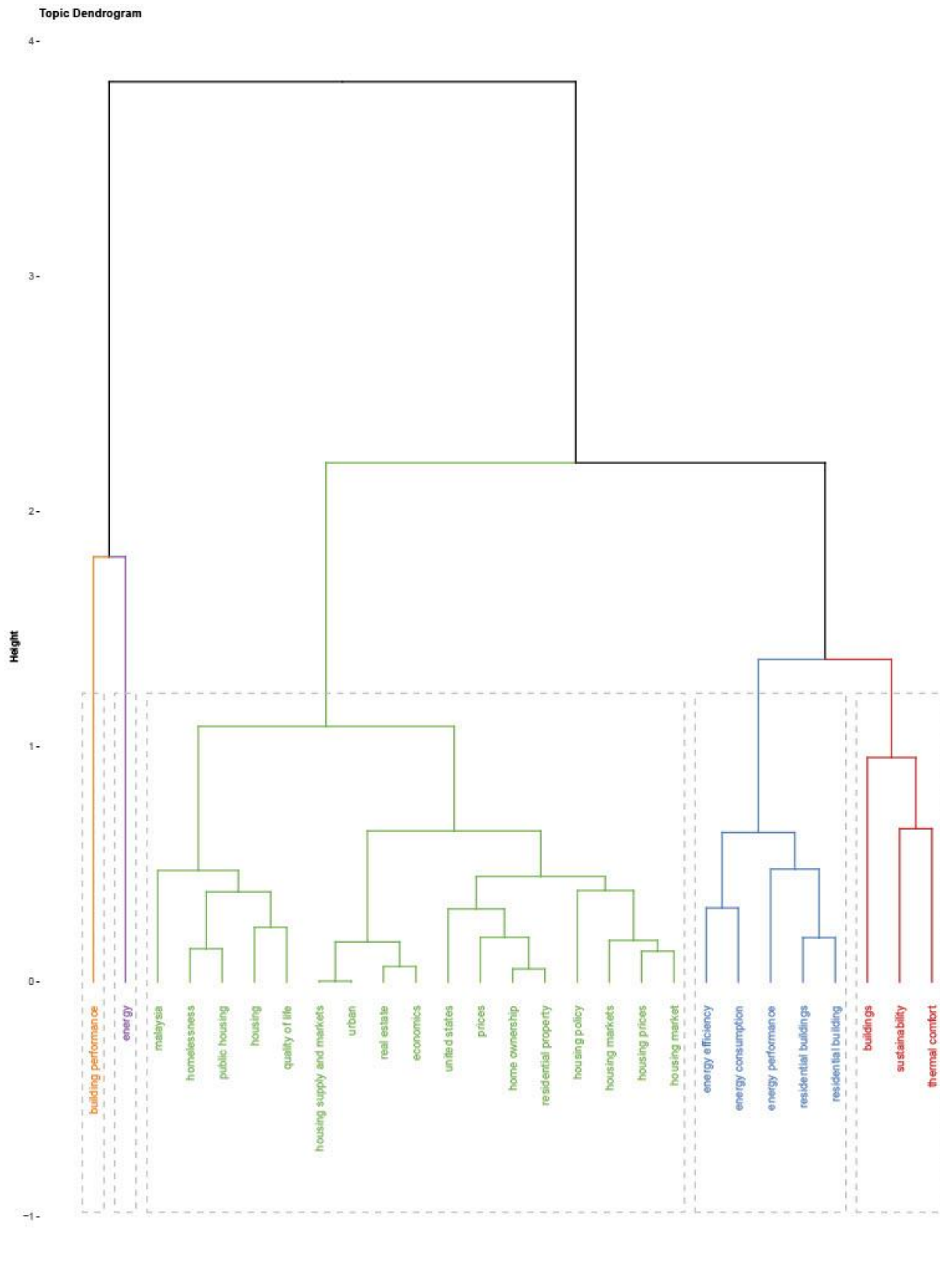

Figure H2: Topic dendrogram

Figure H3: Multi-dimensional scaling graph

APPENDIX I. SCENARIO A2 IMPACT TABLES

Table I1: Developer explicit benefits

Impact	Value
Home sale revenue	450,000

Table I2: Developer explicit costs

Impact	Value
Land acquisition cost	
Purchase Price	83,250
Renovation	
Closing Costs	
Due Diligence	
Development costs	
Sales Commission Costs	**16,650**
Total Construction Costs	274,950
Overhead/other Costs	22,050
Finance Costs	7,650
Marketing Costs	4,500
Carry Costs	

Table I3: Owner-occupier explicit benefits

Impact	Value
Selling Year Transaction Revenue	
Home Sale Revenue	815,113
Homeownership Benefits	
Property Appreciation	
Utility Rebates	
Tax Deductions	0
Home Mortgage Interest Deduction	
State and Local Real Estate Tax Deductions	
Home Equity Loan Interest Deductions	
Home Office Expenses	
Amortization	
Residential Energy Improvements	
Second Home Tax Deductions	

Table I4: Owner-occupier explicit costs

Impact	**Value**
Year 0 Transaction Costs	
House Purchase Price - Year 0	450,000
Down Payment - Year 0	90,000
Financing Costs	
Mortgage Payment	18,534
Mortgage Insurance	0
Property Tax	9,527
Homeowners' Insurance	
HOA Fees	100
Utility Costs	
Energy Cost	1,579
Water Cost	2,625
Maintenance and repairs	4,500
Landscaping	
HVAC	
Plumbing	
Cleaning	
Pest Control	
Replacements	
Capital Gains Taxes	0

Table I5: Owner-occupier intangible costs

Impact	Value	Assumption	
Psychological costs of buying + selling	**553**	1.5-7.9% of home ownership costs before resale, including taxes, maintenance, and utilities	Willingness to pay Zillow home purchasing service charge (Zillow Group, Inc, 2018)
Stress of home maintenance	45	1 % of annual maintenance costs	
Impact of foreclosure on health and well-being	**2,521**		

Table I6: Scenario A2 externalities

Impact	**Value**
Impact in a typical state - first year benefits	365,000
Impact in a typical state - recurring impacts	62,000
Impact on Local Area - first year benefits	323,000
Impact on Local Area - recurring impacts	51,000
Impact of Home Building in a typical local area - first year net benefits	12,680
Impact of Home Building in a typical local area - average year net benefits	3,360
Impact of Home Building in a state and local govt - first year benefits	69,000
Impact of Home Building in a state and local govt - first year costs	25,140
Impact of Home Building in a state and local govt - after first year benefits	16,000
Impact of Home Building in a state and local govt - after first year costs	13,000
Impact of Home Building in a typical local area, state and in a state and local govt- after 15 years benefits	181,000
Impact of Home Building in a Typical State and in a state and local govt- after 15 year costs	121,000

APPENDIX J. SCENARIO B2 IMPACT TABLES

Table J1: Building developer/owner tangible benefits

Impact	Annual Value
Gross potential revenue	21749
Other revenue	1319
Lost revenue	1969
Effective gross revenue	21099
Net operating income	**12429**
Cash flow from operations	**11013**

Table J2: Building developer/owner tangible costs

Impact	Annual Value
Taxes	3457
Salaries and personnel	1818
Contract services	606
Management fees	633
Utilities	517
Repair and maintenance	535
Marketing	410
Administrative	401
Insurance	294
Capital expenditures	1417
Total operating expenses	**8669**
Cash flow from operations	**11013**

Table J3: Building developer/owner intangible benefits

Impact	Annual Value
Development efficiency (difference in cost for a single unit)	420000

Table J4: Tenant tangible benefits

Impact	Annual Value
Building amenities	187
In-unit amenities	78

Table J5: Tenant tangible costs

Impact	Annual Value
Rent	$17,580
Application fees	$10
One-time pet fee	$400
Annual pet fee	$420
Energy cost	1579
Water cost	2625

Table J6: Tenant intangible benefits

Impact	Annual Value
Greater flexibility to downsize or move	
Less than 30 mins commute	2794
Psychological costs of buying + selling	553
Stress of home maintenance	45

Table J7: Tenant intangible costs

Impact	Annual Value
Unpredictable housing expenditures	$30,105

Table J8: Traditional externalities

Impact	Annual Value
Impact in a typical state - first year benefits	$157,000
Impact in a typical state - recurring impacts	
Impact on Local Area - first year benefits	$139,000
Impact on Local Area - recurring impacts	
Impact of Home Building in a typical local area - first year net benefits	$11,320
Impact of Home Building in a typical local area - average year net benefits	
Impact of Home Building in a typical local area - average year net benefits - after 15 years	11000
Impact of Home Building in a state and local govt - FIRST YEAR net benefits	19730
Impact of Home Building in a state and local govt - after first year net benefits	
Impact of Home Building in a Typical State and in a state and local govt- after 15 year net benefits	15000

Table J9: Building Outcomes

Building Outcomes	Annual Value	Assumption
Comfort conditions (benefit to the tenant)	4979	
Crime rate (cost to the owner if in state) (cost to tenant)	552	10% reduction in cost savings per resident per year in Chicago
Daily living - Improved mobility (benefit to the tenant)	218	
Daily living - Personal care technological assistance (benefit to the tenant)	1002	High WTP
Daily living - Kitchen technological assistance (benefit to the tenant)	470	No physically disabled persons in the home (Scenario B2)
Economic growth - find WTP for wealth development	0	
Energy demand - (utility company benefit)	10965	
Energy demand - household benefit (benefit to the tenant)	158	energy demand benefits from a combination of demand reduction and distributed generation
Energy management system (benefit to the tenant)	79	Percentage of annual energy consumption
Energy poverty - food security (benefit to the owner-occupier and tenant)	106104	maintained food security throughout their time in the home (Scenario A2)
Energy poverty - food security (benefit to the tenant)	45072	Experienced mild food insecurity in year 2 or 3 (Scenario B2)
Energy poverty - frequent relocation / housing instability (costs to society)	90	
Energy poverty - health	0	
Energy poverty - educational attainment	0	
Energy poverty - productivity	0	

Energy savings - reduction of energy bills (benefit to the tenant and owner-occupier)	377	building features resulting in annual reductions in carbon dioxide (CO_2) and volatile organic compound (VOC) emissions for which society benefits paid by the homeowner at the time of sale
Energy savings - reduction of CO2 emissions (benefit to society)	384	
Energy savings - reduction of VOC emissions (benefit to society)	190	
Energy savings - application of information technology facilities	8326	
Energy savings - measures (quantify benefits for thermal comfort, air quality, noise protection) (cost to the owner)	2285	modern ventilation system paid for at the time of sale (Scenario B2)
Energy savings - measures	54000	Housing ventilation system (Scenario A2)
Energy savings - measures (quantify benefits for thermal comfort, air quality, noise protection) (cost to the owner)		building features resulting in annual reductions in carbon dioxide (CO_2) and volatile organic compound (VOC) emissions for which society benefits paid by the homeowner at the time of sale (Scenario A2)
Energy savings - measures		New windows as a percentage of the rental price (Scenario B2)
Environmental health - public costs (cost to society)	34146	
Environmental health - children (cost to the tenant)	16	One child in the home experiences pediatric asthma (Scenario B2)
Environmental health - climate change related events and health costs (cost to tenant) (cost to owner)	321	
Environmental impact - household materials and waste reduction (benefit to owner)	18	1% reduction in household materials and waste
Environmental impact - water savings measures (benefit to tenant)	525	
Environmental impact - costs of water and wastewater service disruptions to US household (cost to tenant)	18	

Environmental impact - net benefits to US household of improved water service reliability (benefit to tenant)	1623	
Environmental impact - greenhouse gas emissions - climate change mitigations (benefit to society) what are the costs?	480	
Health outcomes - health care expenditure reduction (benefit to tenant)	576	
Health effects - indoor air quality (benefit to society)	71	Asthma and allergens
Health effects - weather and natural disaster resistance (benefit to owner)	15	
Health effects - disaster-related response plans (benefit to society)	3	FEMA mitigation grants total
Health effects - Weather and natural disaster resistance	4	Above-code design (Scenario A2)
Health effects - noise abatement (benefit to tenant)	562	
Thermal discomfort	87	Scenario A2
Thermal discomfort (benefit to tenant)	35	Scenario B2
Housing affordability (costs to tenant)	0	
Housing needs - benefits to tenant	8	
Sleep quality (benefits to tenant)	3069	
Social interaction (benefits to tenant)	142	
Social capital (benefits to tenant)	5757	
Social relations (benefits to tenant)	554	
Sustainable development	2458	1% of green commercial building value (Scenario A2)
Sustainable development (benefit to tenant)	912	
Energy management system - technology attribute interaction (benefit to tenant)	13	

Energy management system - attitudes, behaviors, and social influence (benefit to tenant)	25	
Energy management system - system and infrastructure expectation (benefit to tenant)	13	
Housing needs - benefits to society	22	
Environmental health - environmental justice communities - infant mortality (cost to society)	82	
Housing affordability - cost to society	17550	
Housing needs - benefits to owner	8	Scenario B2

APPENDIX K. D-NPV ASSUMPTIONS

Rate of returns		Rate	Reference
Actual appreciation rate	Scenario A2 risk of lower-than-expected revenues	2.66	Shilling (2003)
Expected appreciation rate	Scenario A2 risk of lower-than-expected revenues	0.92	Shilling (2003)
Real capital gain in the U.S.	Scenario A2 and B2 risks of higher-than-expected costs	0.90	Jordà, Knoll, Kuvshinov, Schularick, and Taylor (2019)
Mean rate of return for real capital gain	Scenario A2 and B2 risks of higher-than-expected costs and lower-than-expected revenues	2.39	Jordà, Knoll, Kuvshinov, Schularick, and Taylor (2019)
Mean rate of return for real capital gain in the U.S.	Scenario A2 and B2 risks of higher-than-expected costs and lower-than-expected revenues	3.54	Jordà, Knoll, Kuvshinov, Schularick, and Taylor (2019)
Average expected return	Scenario B2 risk of higher-than-expected costs and lower-than-expected revenues	6.51	Shilling (2003)
Actual return	Scenario B2 risk of higher-than-expected costs and lower-than-expected revenues	4.30	Shilling (2003)
Mean rate of return for rental income in the U.S. (real)	Scenario B2 risk of lower-than-expected revenues	5.33	Jordà, Knoll, Kuvshinov, Schularick, and Taylor (2019)
Real returns on housing	Scenario B2 risk of higher-than-expected costs and lower-than-expected revenues	6.59	Adopted from Piazzesi, Schneider, and Tuzel (2005)
Real returns on housing	Scenario B2 risk of higher-than-expected costs and lower-than-expected revenues	1.8	Piazzesi, Schneider, and Tuzel (2005)

NPV SENSITIVITY

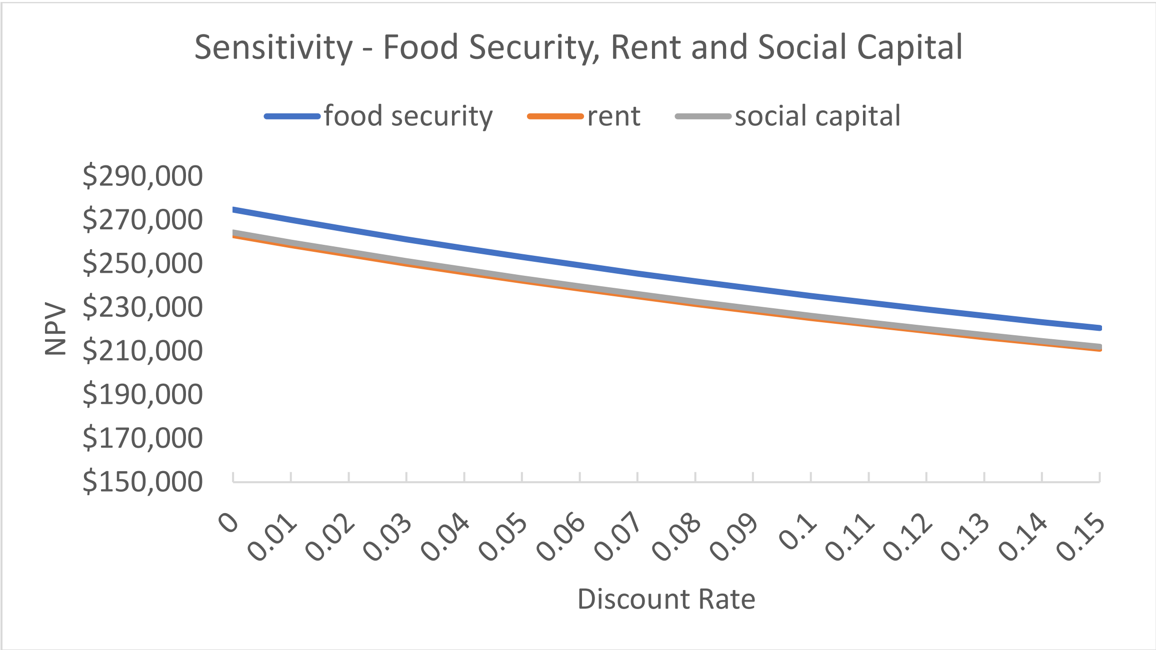

Figure K1: Scenario B2 Sensitivity – Food Security, Rent and Social Capital

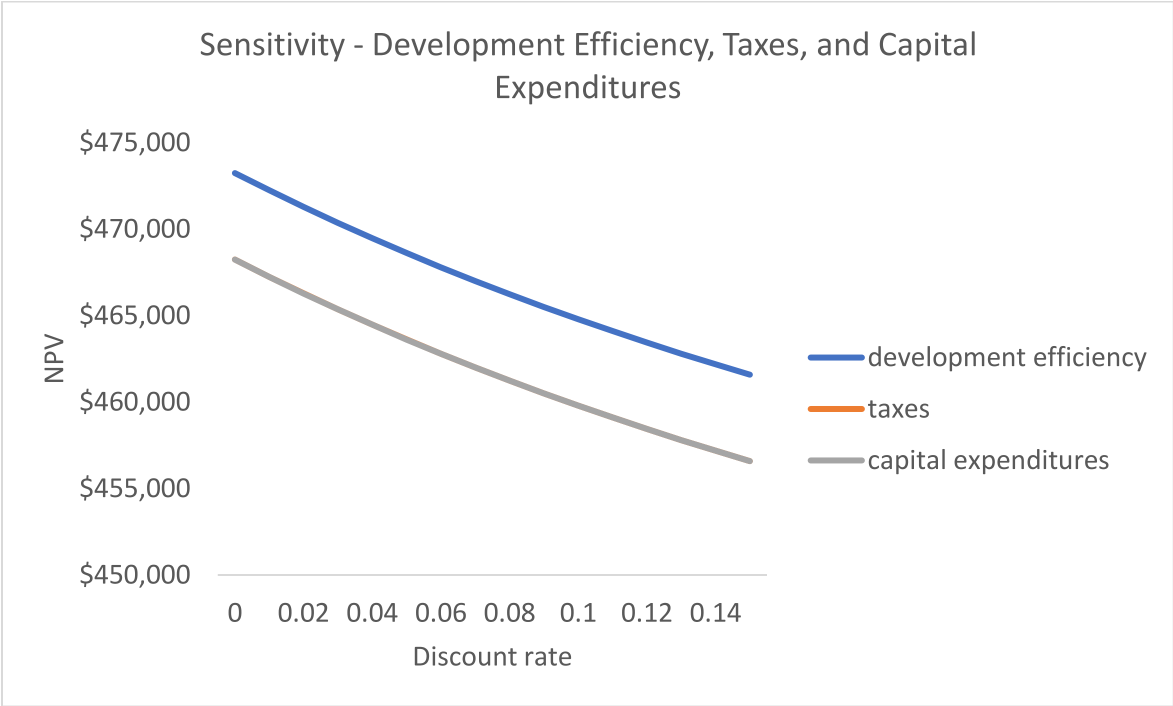

Figure K2: Scenario B2 Sensitivity – Development Efficiency, Taxes, and Capital Expenditures

APPENDIX L. DECONSTRUCTION OF RESIDENTIAL REAL ESTATE BUSINESS MODELS

A single-case analysis of 10 residential real estate companies' flow of value is described. Company cost structures were not documented or discussed for brevity.

AvalonBay

AvalonBay Communities, Inc. and its subsidiaries develop, redevelop, acquire, dispose and operate multifamily communities in the U.S. to achieve the financial goal of long-term shareholder value creation. AvalonBay Communities, Inc. is likely taxed as a C-Corporation as a Maryland corporation real estate investment trust (REIT) and referred to as “AvalonBay” in the text.

AvalonBay creates value by manufacturing, lending, and adding value to physical assets. AvalonBay manufactures physical assets such as multi-use developments that may include infrastructure and multifamily communities. AvalonBay Communities acquires and disposes of communities; AvalonBay may act as a distributor of physical assets if communities did not undergo development. AvalonBay lends physical assets as it owns and leases apartment communities and retail space. This company also redevelops multifamily communities creating value from the value added to a physical asset.

AvalonBay captures value from manufacturing and adding value to physical assets through asset sales, development, and redevelopment fees. The sale of condominiums follows a single payment structure where value is captured instantly at the time of sale. The real estate pricing is model-based. Management – asset and property management, development, and redevelopment – fees are recognized monthly, likely in the form of a time-based subscription or continuous payment based on usage. These management fees presumably follow a value-based pricing model because the service fees are connected to measured progress toward a performance obligation.

The company captures value from lending physical assets in from rent, rental-related, and non-rental related income. The company employs a model-based pricing model using revenue management software to optimize pricing and leasing terms as a function of market conditions, occupancy, pricing, lease expiration, and traffic patterns. Leasing terms are typically one year or less, and rental income is recognized on a straight-line basis following a subscription time-based payment structure. Rental-related income such as reservation fees and application fees likely follow an instant, single payment structure. Reservation fees follow a model-based pricing model as a function of the base rent on a per-diem basis and the number of days between the lease application and termination. Application fees follow a cost-based pricing model to cover the application processing cost. There is no pricing or payment structure information available on the non-rental related income.

AvalonBay also creates value from services. They manufacture services through asset and property management teams, design construction services as a third-party construction manager, and aggregate services as a third-party general contractor. Their roles as a third-party service likely follow a cost-based pricing model realized monthly with the other management fees. Through a taxable REIT subsidiary, this company arranges ancillary services for residents and may or may not directly share in the revenue or income from these services, positioning them as a connector of services in the former case or broker of services in the latter. This income may be the non-rental related income for which there is no information.

Their property management service follows a direct engagement strategy. On-site leasing, operation, and maintenance activities illustrate a high engagement sales strategy to residents. An online portal, email, and phone number to the customer care center are a high engagement channel to efficiently address resident needs delivering on measures of comfort and speed. The official company website enables direct, comfortable, low engagement for current and potential stakeholders.

AvalonBay offers functional, economic, and experiential value to different customers segmented by their job and needs. Retailers (job group) and apartment renters (need group) who need to borrow space receive a functional benefit from AvalonBay's retail and multifamily space lending, respectively. AvalonBay also aims to provide economic value to space borrowers by developing in high-density urban/metropolitan areas with high homeownership costs and growing employment in high-wage economic sectors, as well as optimal retail space conditions. Multifamily community brand differentiation enables AvalonBay to expand in existing markets by targeting apartment residents by consumer preference, attitude, location, and price. On this note, residents are offered experiential value such as convenience to necessities and amenities and ancillary services for improved resident satisfaction and alignment with their strategic vision of "*Creating a Better Way to Live*." Two need groups receive a functional benefit of AvalonBay's role as a manufacturer or adder of physical assets. First, infrastructure participants benefit from its manufacture. Second, homebuyers receive a functional benefit from the multifamily communities. Developers, re-developers, and building owners (job groups) receive a functional benefit from their design and aggregation of services. Building owners and re-developers, also job groups, receive a functional benefit from AvalonBay's disposition of properties.

AvalonBay's organizational resilience is focused on protecting its physical assets. Preventative maintenance is their organizational means to anticipate value disturbance to their physical assets. AvalonBay purchased supplies in bulk, acquired goods/services from pre-approved vendors using nationally negotiated contracts, bidding third-party contracts on a volume basis, and was directly involved in construction to prevent disturbances to their physical assets value creation by controlling costs, schedules, and quality. Joint ventures and partnership agreements protect from risks associated with the physical asset (i.e., asset concentration) or add development or operational expertise to the venture. They use insurance as an organizational means to absorb any disturbances to value and pursue real estate tax appeals as a legal means to recover value from disturbances. Their property management pricing software is an intangible asset that enables AvalonBay to anticipate value disturbance by making informed leasing and maintenance decisions using financial and resident data to control costs and maximize revenue. Long-term conditional contracts for target land sites are legal means to anticipate value disturbances to financial assets by limiting development-related risks conserving capital. Maintaining discretionary real estate investment funds as part of their acquisition strategy was another organizational means to achieve growth, acting as investment facilities for recovery from value disturbances to their financial assets. Similarly, joint ventures and partnerships can provide liquidity to recover from value disturbances to financial assets. On-site property management teams receive bonuses to prevent value instabilities with human assets.

AvalonBay's competitive strategy is primarily focused on maintaining stability in its product-market domain. Their ability to use long-term conditional contracts in their acquisition strategy was exemplary of stability. Their operations are efficient along at least three avenues. First, operating efficiency, high-efficiency building energy and water systems, and preventative maintenance maximized property and equipment life. Second, supply chain efficiency from direct involvement in construction and timely transition to the leasing and operating phase. Last, the customer care center consolidated administrative tasks associated with owning and operating apartment communities. AvalonBay differentiated its company with strong culture enabled by its hard-working and talented regional development and operational teams. Also, AvalonBay differentiated its multifamily communities through brand differentiation and extensive and ongoing maintenance programs.

This Company likely manages value using a matrix organizational structure with regional offices in local markets composed of dedicated development and operational teams and administrative and principal offices in Arlington, VA. The Company "buys" regional talent to support this management structure, with the occasional outsourcing of community leasing/maintenance activities, and employs third-party general contractors as construction managers for certain mid-rise and high-rise apartments. In-house development and redevelopment teams sustained by their in-house acquisition platform enable the Company's development and redevelopment activities. Also, the Company procures goods and services in bulk from pre-approved vendors through national contracts and bids for third-party contracts on a volume basis. AvalonBay builds and purchases the facilities necessary to create value. The Company builds communities in metro areas that are likely to yield high risk-adjusted returns over the long-term on apartment community investments expected from an area's vibrancy, rising employment, and higher cost of homeownership. Also, the Company builds retail space to improve community attractiveness for potential residents or when required to by the local government. Land, existing communities, and other assets are the "facilities" purchased to create value. The Company buys land acquisition before construction for extended periods while entitlements are obtained, including land zoned for non-residential uses with the potential for rezoning. Existing communities and other assets may be purchased to achieve the desired product mix or to rebalance their portfolio. Vacant land, land with improvements, and existing communities in "locations near expanding employment centers and convenient transportation, recreation areas, entertainment, shopping, and dining are purchased" (AvalonBay Communities, Inc., 2019). The Company borrows capital as part of a financing strategy. The Company built capital through the disposition of communities, offers shares of equity securities and debt securities.

AECOM

AECOM is likely taxed as a C-Corporation in Delaware. AECOM has a divisional organizational structure with four separating operating segments – Capital (ACAP), Construction

Services (CS), Management Services (MS), and Design and Consulting Services (DCS) - creating value across many asset types. AECOM manufacturers and designs physical assets, services, and outcomes; lends financial and human assets; and manufactures intangible assets and knowledge/content/data. AECOM CS manufacturers physical assets, including the construction of large-scale building and facility construction projects such as modern office and residential towers, and designs construction management services for these types of projects. On that note, AECOM CS designs outcomes through program management services for large-scale building and facility construction projects. AECOM DCS designed physical assets through architectural and engineering, and design services. Also, AECOM DCS designed construction management services, lends human assets for planning and consulting services, and designs outcomes through program management. AECOM Capital (ACAP) lends financial assets, investing in real estate projects, particularly build-to-core Co-GP equity investments or value-add repositions of commercial real estate assets. AECOM MS manufactures intangible assets such as IT infrastructure design and implementation. AECOM MS manufactures outcomes through program and facilities management, training, logistics, consulting, technical assistance, systems integration, and information technology services. AECOM MS manufacturers services such as the operation and maintenance of complex government installations, including military bases and test ranges; and management and operations and maintenance services for complex DOE and NDA programs and facilities; operation and maintenance of complex government installations, including military bases and test ranges. AECOM MS manufactures physical assets, planning, designing, and constructing barracks, military hospitals, and other government buildings. AECOM MS manufactures knowledge/content/data for planning and conducting emergency preparedness exercises and first responder training for the military and other government agencies. Also, AECOM MS designed services for government sites. AECOM CS designed physical assets infrastructure such assets power-generating facilities and power transmission and distribution systems.

ACAP creates value from real estate development sales as an instant, single-payment priced based on value. AECOM captures value primarily on a fee-for-service basis using cost-reimbursable contracts, guaranteed maximum price contracts, and fixed-price contracts. Cost-reimbursable contracts follow a cost-based pricing structure as clients are charged a cost-plus fixed fee or rate and time-and-materials payment structures. The revenue recognized for a cost-plus fixed fee or rate contract follows two payment mechanisms. Reimbursement for the actual, direct and indirect costs incurred demonstrates continuous payment based on usage. The fixed fee or rate typifies a delayed, single payment recognized at a specific date. Some cost-plus contracts followed a value-based pricing model either by providing award fees on a penalty based on performance criteria or a base fee plus a performance-based award fee instead of a fixed fee or rate assuming the previously mentioned payment structure. Under time-and-materials contracts, payment is continuous and based on usage (e.g., the time spent on the project and the cost for materials and incidental expenditures). Additionally, time-and-materials contracts may have a fixed-price requirement (e.g., not-to-exceed or guaranteed maximum price). Lump-sum and fixed-unit price contracts constitute fixed-price contracts. Revenue from these contracts was recognized using the input method measured on a cost-to-cost basis illustrating a cost-based pricing model. On the former, a specified fee is charged for the work performed, following a delayed, single payment structure. On the latter, AECOM performed units of work at an agreed price per unit with the total payment under the contract determined by the actual number of units delivered following a volume-based subscription payment structure. Guaranteed maximum price contracts resemble the typical cost-plus and fixed-price contracts in pricing and payment structure with the stipulation that clients are assured a total price for the project and additional project costs will likely be the responsibility of AECOM. Under cost-plus contracts, all project costs are disclosed, and a lump sum percentage fee is stated. AECOM revenue is primarily generated from pass-through fees from subcontractors and other direct costs and the services provided to clients. CS and MS segments incur pass-through costs. DCS revenue was derived mainly from fees instead of pass-through costs. ACAP captures value from management fees and real estate development sales. The value captured from real estate development sales is instant, single payment likely with a market-based pricing model as an internal model was not explicitly stated.

Contact information for regional offices on an official website indicates a comfortable, direct, low-touch engagement sales strategy. It can be inferred by the nature of the services offered AECOM employs an overall direct sales strategy directly working with the client either on-site (high engagement) or remotely (low engagement). Due to a consistent emphasis on quality, cost, and planning, AECOM aims to deliver accuracy and speed.

AECOM provides functional value for specific job groups such as governments, businesses, and organizations globally. ACAP works with national, state, regional, and local governments, public and private institutions, and major corporations. CS delivers to local, state, federal, and national governments and corporations involved in the buildings and energy sectors, mainly in the Americas. DCS works with commercial and government clients worldwide in major end markets such as transportation, facilities, environmental, energy, water, and government. MS is often retained by national government agencies in the U.S. and U.K.

AECOM prevents disruptions in managing physical assets by utilizing redundancy by purchasing raw materials and other inputs from numerous sources. Confidentiality policies, trade secrets, and contract agreements legally prevent value disturbance to their intangible assets (e.g., intellectual property). Joint ventures and partnerships allow AECOM to earn equity from physical assets. Pass-through contracts are an organizational means to recover direct costs incurred on projects on behalf of the client for project continuity. Also, to prevent value disturbances during project execution, the final price of guaranteed maximum performance contracts may not be set until a significant percentage of the trade contracts are in alignment with the master contract are negotiated. AECOM also diversifies its clientele as only the U.S. federal government has been the only client over five years to account for 10% or more of their revenue. Surety bonds and unsecured credit facilities are organizational guarantees to clients of their ability to absorb and recover financial damages respectively in the event of underperformance of project executions. Maintaining a low leverage balance sheet allows minimizes the Company's vulnerability in an economic downturn, increasing its potential to absorb economic instabilities. To ensure human assets are secured with the Company, a portion of U.S. employees join with collective bargaining agreements foiling potential disturbances to value through employee attrition.

To sustain their competitive position, AECOM acts primarily as a defender with a prospector's efficiency perspective. As a prospector, AECOM catered to clients with their worldwide technical expertise to increase its operating efficiency, not solely cost-effectiveness like a defender seeking to maintain stability. AECOM stabilized their position by cultivating customer loyalty and long-term customer relationships, differentiates themselves with experienced operational teams and affordable product offerings across multiple brands, depicts their experience with an expansive set of services, and illustrates their reach with industry-leading market share, broad geographic footprint, reputation, and an extensive, international network of offices are organizational stability indicators for defenders protecting their share.

DRHorton

DRHorton is likely taxed as a C-Corporation as it is a Delaware corporation. DRHorton creates value from manufacturing physical assets such as single-family detached homes, attached homes (e.g., townhomes, duplexes, and triplexes), ranch land, land for development, and owns and operates oil and gas-related assets. Other subsidiaries like DHI Communities manufacture and lend physical assets (multi-family rental properties). Their subsidiary, Forestar, distributed physical assets such as land and residential lots or manufactured services for those physical assets by providing planning and management activities related to the entitlement, acquisition, community development, and sale of residential lots. Another subsidiary, DHI Mortgage, manufactures and lends financial assets such as title insurance and mortgages, respectively. Correspondingly, DHI Mortgage manufactures title agency services to support its title insurance offering. DRHorton will also act as a connector of services in offering other mortgage lender information to homebuyers.

Their single-family detached homes and attached homes (e.g., townhomes, duplexes, and triplexes) offer the homebuyer demographic, functional value of buying a home, and economic value with offerings across different price points. Moreover, they deliver economic value by catering to different psychographic homebuyers such entry-level, first-time, first-time move-up, relocating in a short time frame, higher-end move-up, luxury, and those preferring an affordable and low-maintenance lifestyle; and homebuyers with specific needs such as speculative homebuyers.

DRHorton purchased land/lots to build on them but may sell them for strategic reasons. In these cases, the sale of residential land and lots, typically single-family lots, provides functional value to homebuilders. Similarly, commercially zoned parcels may be sold to commercial developers as lot and land sales on occasion. The functional value of servicing rights and mortgage loans is sold to the job group of third-party mortgage loan purchasers.

The value created from homebuilding was primarily through the sale of those homes. Other income consisted of interest income, rental income, and other ancillary income not directly associated with home, land, and lot sales. Forestar creates value from residential land and lot sales and commercial lot sales. The financial services segment captured value from loan origination fees, sale of servicing rights and mortgage loans, and title policy premiums. A market-based pricing strategy was assumed because no information regarding an internal model was identified. DRHorton's revenue is mainly from homebuilding. Revenue from the sale of completed homes, land, and lots are instant, single payments dependent on market-based pricing recognized at the closing of a sale. Rental income is a subscription time-based payment format dependent on market-based pricing. Interest income is a continuous payment earned from the loan origination date based on usage (the interest-bearing amount of the mortgage loan) assumed to be near the market-based price of the home. There were no specifics provided on the ancillary income. Revenues associated with title services and issuing title insurance policies are recognized at the closing of a sale, likely as title policy premiums. In this case, it can be assumed that the premium is an instant, single payment priced at a company-decided rate and the home purchase price (model-based pricing). Similarly, loan origination fees were recognized at the time of origination and assumed to be instant, single payments. The sale of mortgage loans and their servicing rights follow are instant, single payments priced using at fair value accounting for expected net future cash flows related to the loan servicing (model-based pricing).

DRHorton conveyed its products using pull promotions and push and pull advertisements. DRHorton employed a brand campaign to their homes and communities to the specific audiences mentioned previously (a direct pull strategy) to raise awareness about their homes and communities. Also, they engaged an indirect pull strategy by directing promotional activities to local real estate brokers and depending on industry and homebuyer referrals. This company utilized direct push advertisements of their value to raise awareness, remain in consideration, and convert prospective homebuyers and their real estate brokers through email marketing, catalogs of floor plans, pricing, options, and features assistance. Incentives, discounts, and free upgrades are direct push conversion aims. These same audiences were targeted, alerted to DRHorton's offerings using indirect pull strategies such as print media and advertising, billboards, radio, television, magazine, and local newspaper advertisements; search engine marketing; other real estate websites; and social media. To remain in the customer's thought, this company advertises on other real estate websites.

DRHorton delivered value using a secure, direct high-engagement avenue. Sales occur place at sales offices and model homes (affiliated facility) by in-house personnel. In-house sales and marketing personnel and independent real estate brokers were presumably credible, direct and indirect sales channels, respectively. The official website is a comfortable, direct, low engagement means to learn more about and connect with the company, search for homes, and learn about their homes.

The organization exercised service contract redundancy, procuring construction material contracts from numerous sources exceeding one year and cancelable at company discretion to prevent project construction disruptions. Similarly, joint ventures prevented physical assets' value creation disturbances by lowering risk and gaining necessary organizational support. Subcontractors provided craftspersonship warranties and remained available to fix homeowner issues to absorb disturbances to the physical asset value. Similarly, some suppliers provided manufacturer warranties on installed products. To absorb value disturbance’s as a company, DRHorton has multiple business models available for expansion to compensate for value losses in other segments. To legally prevent value disturbances to land/lots, DRHorton acquires land/lots using non-recourse option contracts. Their physical asset inventory depended on the economic environment and market studies for potential impairment indicators; as an organizational strategy to anticipate value disturbance to these financial assets. Geographic diversification of their physical assets was an organizational strategy to limit their exposure to unsystematic asset-related risk events. Likewise, DRHorton’s continuous cost monitoring of inventory levels, land development expenditures, and construction costs aid in maximizing asset returns. Sales commissions incentivize human assets, and knowledge sharing within local management teams can circumvent disturbances to talent value creation. To further prevent disruption to value creation, sales personnel are trained on the availability of financing, construction schedules, and marketing and advertising plans.

DRHorton defends its competitive advantage by maintaining stability leveraging economies of scale, achieving operational efficiency by controlling costs, capital, materials and labor, construction and operating activities, and sustaining their reach in existing geographical coverage in 27 states and 81 markets. DRHorton takes a defender’s approach to product and service quality with 1) pre-closing quality control inspections and post-closing customer's needs assessment, 2) construction superintendents’ engagement homebuyers providing information during the construction process and on post-closing home maintenance, and 3) limited warranties structural elements, major mechanical systems, and other components. Pre and post-closing services and warranty repairs are intended to secure their customer base through a good customer service experience. DRHorton sold residential lots to quality homebuilders who uphold community standards to maintain their brand associated with quality. To sustain and grow their customer base DRHorton acts as an analyzer competing on quality, price, location, design, and mortgage financing terms. As an analyzer, DRHorton's competitive advantage was adopting new but proven products and matching them to the market. On this note, customizable home options and feature upgrades, and selective advertising and site locations welcomed a targeted and personalized customer experience. A key differentiator is the local management teams' competency to tailor product offerings to match customers' expectations regarding affordability, home size, and features. Their emphasis on developing high-quality assets and home design capabilities exhibits an analyzer's approach to efficiency.

DRHorton is likely a divisional organization structure with centralized management structure as corporate executives and office departments "are responsible for direct management of key risk elements and initiatives through centralized functions" and "establish operational policies and internal control standards"; local managers responsible for homebuilding operational decisions, and 46 operating divisions (DRHorton, 2018). To achieve the benefits of national, regional, and local scale of operation, the Company "borrowed" talent and "bought" materials from specific suppliers. This Company "borrowed" talent from subcontractors for lower labor rates for land development and home construction work. DRHorton "bought" construction materials from numerous sources for volume discounts and rebates from national, regional, and local materials suppliers. The Company buys land and lots through a small number of joint ventures through the Forestar Group Inc. The Company borrows capital with stable access to a lower cost of capital due to its "balance sheet strength" and "capital markets relationships."

Realogy

The legal structure of Realogy Holding Corp. is likely a C-corporation, and the legal structure of Realogy Group LLC is an LLC taxed in Delaware with principal executive offices in New Jersey. The Company will be referred to as Realogy for the remainder of the text. Four operating segments established Realogy: 1) Real Estate Franchise Segment (RFG), 2) Company Owned Real Estate Brokerage Services (NRT), 3) Relocation Services (Cartus), 4) Title and Settlement Services (TRG). The brokerage services, RFG and NRT, brokered physical assets. Also, NRT participated in a mortgage origination joint venture, characterizing it as a lender of financial assets. The Relocation Services segment acted as a connector of human assets. The RFG segment manufactured and lent intangibles assets; and manufactured knowledge, content, and data to support franchisees—all four operating segments manufactured services. Firstly, TRG manufactured full-service title and settlement services. Secondly, RFG helped franchisees with national marketing and servicing programs. Thirdly, NRT offered homeownership services. Lastly, Cartus offered global relocation services. Moreover, Cartus acted as a broker of services.

Realogy's revenue is derived on a fee-for-service basis; fees are collected from different aspects of a residential real estate transaction. RFG captures value using model-based pricing models to determine royalty fees, marketing fees, area development fees for international territory transactions, and initial franchise fees for domestic transactions. Royalty fees are accrued as the franchisee revenue is earned, suggestive of usage-based, continuous payment. Franchisees could pay royalties following a capped model fee (a royalty fee capped at a set amount per independent sales agent per year) or a flat fee model (typically 6% of the gross percentage of the franchisee's gross commission income), and both options were subject to franchisor business conditions. The marketing fees were recorded as deferred revenue and later recognized as earned revenue when spent, indicative of a delayed, single payment structure. The initial domestic franchise fees were recognized at the execution or opening of a new franchisee office follow an instant, single payment structure. Area development fees were recorded as deferred revenue when received and recognized as revenue over the average life of the franchise agreement, indicative of continuous payment of installments. NRT captures value as real estate commissions earned from home sales and purchases. These fees are recognized at closing and determined by an internal model, evidential model-based pricing, and an instant, single payment structure. Value from Relocation Services was captured from outsourcing management fees, referral commissions, and interest income. Outsourcing management fees are typically billed at the start of the relocation service and recognized either at a phase of the move covered by the fee or over the average period required to complete the transferee's move. This payment structure may be indicative of continuous payments of installments. The referral commission revenue for home sales and purchases was recognized as an instant, single payment at the sale closing. The referral commission revenue for third-party service providers was recognized after the services, suggesting a delayed, single payment. Model-based pricing methods set the referral commission and outsourcing management fees. The interest income from funds advanced on behalf of the relocating employee is recorded within other revenue; the pricing method and payment structure were unclear but likely followed a cost-based pricing method. TRG revenue is captured through title and service closing fees at the closing of a home sale or refinancing transaction and underwriting policy premiums upon notice of policy issuance from the agent. These fees are priced using models and follow an instant, single payment exchanged when value was received.

Realogy delivered value through direct high engagement at affiliated facilities using brokerage offices with independent sales agents and direct low engagement through their official website. RFG delivered value using direct low-engagement approaches such as an internet-based reporting system for domestic franchisees to transmit listing and other relevant information electronically and owning and operating consumer websites for each brand to empower speedily and comfortable value delivery. The Cartus Network member referrals are an indirect push promotion method to increase awareness, consideration, and conversion with potential home buyers and sellers.

Realogy offered functional value by specific job groups. RFG offered functional value to franchisees and independent sales agents. Moreover, NRT offered functional value to developers in major cities to service their new developments. Relocation services provided functional value to members of the Carter Broker Network real estate brokers (from company-owned brokerage operations, select franchisees, and independent real estate brokers), other real estate brokers, and third-party service providers. TRG offers functional value to the need-based segment of home buyers and sellers; and job-based segments of real estate companies, affinity groups, corporations, and financial institutions. NRT pursues the large U.S. metropolitan area demographic of home buyers and sellers, borrowers, rental homeowners to offer the functional value of a home. RFG fulfills the functional value of needing to sell or purchase a home to franchisees' customers. Relocation services aim to provide experiential value to job groups, corporate and government organizations, 56% of this segment are Fortune 50 companies, their employees (transferees), and affinity organizations such as insurance companies and credit unions.

The Company protects value through trademarks, technological innovation, a compelling and accessible knowledge base, multiple business models, diversification, contracts, and training. A plethora of trademarks for different brands legally prevent the disruption of value created from the intangible assets critical to this franchise model. Technological innovation through ZapLabs was an essential intangible asset to anticipate and prevent value disruption in each business segment. ZapLabs is the innovation, technology, and big data hub for Realogy. Realogy data and technology products and services (i.e., Zap technology platform and internet-based data reporting platform) were critical to effectively supporting the productivity of independent sales agents and franchisees in RFG and NRT. RFG technology offerings are frequently revised to highlight the value proposition of each brand and meet the evolving needs of brokers, agents, and consumers. RFG uses a proprietary Zap technology platform for lead generation, predictive customer relationship management at all transaction stages, mobile application and website listing distribution access, additional home sale transactions access, client insight and behavioral data, and a comprehensive, streamlined consumer home-related transaction experience. Realogy's real estate industry insight, robust relationships with real estate brokers, sales agents, and other real estate professionals, and expertise across the transactional process were superior capabilities to prevent value shocks to Realogy's business model. RFG's know-how drives the national marketing and servicing programs bought into by franchisees. Partnerships with a nationwide network of attorneys, title agents, and notaries prevent disturbances to the value created by TRG. Realogy uses revolving credit facilities to recover financial assets value disturbances. The use of four complementary business models and the mortgage joint venture work together to enable value creation from multiple points in a residential real estate transaction. The operation of multiple brands enables value creation from different segments of the residential real estate market. These multiple business models are intangible assets that permit the absorbance of value creation disturbances to anyone Realogy's business models. Diversification was a strategy employed by RFG to avoid value disturbances to financial assets; other than NRT, no franchisee produces more than 1% of their total revenue. Franchise agreements legally secure the human assets that create value for the brokerage businesses by restraining franchisees' terminating agreements prior to their expiration. Knowledge sharing of data and business-enhancing tools bolstered talent productivity and profitability. For example, RFG provides franchisees with training, education, learning, and development to preclude shocks to value created by human assets.

Realogy primarily acts as a defender to maintain its competitive advantage but maintains efficiency like a prospector. Their stability is evident in their claim to be the leading and most integrated residential real estate services provider. For example, the RFG segment exhibits multiple stability characteristics in long-term domestic franchise agreements of 10 years, average U.S. franchisees tenure of approximately 22 years, and 98% franchisee retention rate (illustrating customer loyalty). Similarly, the top 25 relocation clients for Relocation Services had an average approximate tenure of 20 years. Realogy differentiated its business as an integrated offering claiming to be an integrated provider of residential real estate services in the U.S., offering more than two services to progress and simplify the home transaction process. Realogy focuses on providing a streamlined and smooth customer home transaction experience at each business segment through wide-ranging customer service. For example, their extensive range of first-rate employee relocation services intentionally manages all aspects of an employee's move to assist a smooth transition. Brand recognition, their broad customer base, and geographic coverage demonstrated their reach as a fundamental advantage. Realogy owns some of the most recognized real estate industry brands such as Coldwell Banker, Better Homes and Gardens, and Century 21. Also, Realogy operates at varying price points in many different geographies with 16K offices worldwide in 113 countries, 6K U.S. brokerage offices, managing over 171,000 corporate and affinity relocations in 150 countries for roughly 660 active clients (Realogy Holdings Corp. and Realogy Group LLC, 2019). Process innovation was a critical component to their competitive advantage, as shown by the transformative consumer, agent, and broker technologies created at ZapLabs.

Realogy borrowed or bought facilities to own and operate the "leading residential real estate brokerage business in the United States" (Realogy Holdings Corp. and Realogy Group LLC, 2019).

Realogy built and bought talent, as shown in the following statement:

> "The core of our integrated business strategy is to grow the base of productive, independent sales agents at our company-owned and franchisee brokerages and provide them with compelling data and technology products and services to make them more productive and their businesses more profitable" (Realogy Holdings Corp. and Realogy Group LLC, 2019).

Another example of building talent to manage value is the Cartus Broker Network. "Member brokers of the Cartus Broker Network, including certain franchisees and NRT, receive referrals from the relocation services, affinity services, and from each other in exchange for a referral fee." As a result, 53,000 of TRD's 176,000 closed transactions of TRG were related to NRT.

Realogy buys and builds intellectual property (Realogy Holdings Corp. and Realogy Group LLC, 2019):

> "Our operating platform is supported by our portfolio of industry-leading franchise brokerage brands, including Century 21®, Coldwell Banker®, Coldwell Banker Commercial®, ERA®, Sotheby's International Realty®, and Better Homes and Gardens® Real Estate."

> "We are the largest franchisor of residential real estate brokerages in the world through our portfolio of well-known brokerage brands, including Century 21®, Coldwell Banker®, Coldwell Banker Commercial®, ERA®, Sotheby's International Realty®, and Better Homes and Gardens® Real Estate. In January 2019, to expand and enhance our existing portfolio of brands, we launched Corcoran® as a new franchise brand, which has historically been operated solely as part of our company-owned brokerage segment."

Cherry Hill

Cherry Hill Mortgage Investment Corporation's legal structure is a Maryland corporation taxed as a REIT (Cherry Hill Mortgage Investment Corporation, 2018) and referenced as Cherry Hill in the remaining text. The organizational management structure was nil because Cherry Hill has no employees. Aurora has a nominal number of employees and is externally managed, owned, and controlled by Cherry Hill Mortgage Management, LLC. The Company borrows talent from third-party sub-servicers for loan servicing functions associated with MSRs.

The Manager of Cherry Hill Mortgage Investment Corporation was party to a services agreement with Freedom Mortgage Corporation, LLC, owned and controlled by the Manager. Both companies are reviewed to understand the business. Cherry Hill lends financial assets. This Company invests in residential mortgage assets, prime residential mortgage loans, and other cash-flowing residential mortgage assets, RMBS including Agency RMBS, residential mortgage pass-through certificates, CMOs (IOs and inverse IOs), and TBAs; servicing Related Assets consisting of MSRs and Excess MSRs. Also, Cherry Hill manufactures services by building and managing a portfolio of servicing-related assets and RMBS using a licensed mortgage servicing subsidiary ("Aurora"). Freedom Mortgage lends financial assets as mortgage origination and servicing and adds value to financial assets through loan refinancing options.

Value is captured by recognizing revenue for securities, investments in Excess MSRs, and investments in MSRs. Interest income for investments in securities is collected as a usage-based continuous payment in the form of coupon payments accrued based on the outstanding principal amount of the RMBS and its prescribed terms (Cherry Hill Mortgage Investment Corporation, 2018). Value is captured from Excess MSRs as interest income projected from the excess servicing amount over the anticipated life of the mortgage (Cherry Hill Mortgage Investment Corporation, 2018). Value was captured from investments in MSRs as mortgage servicing fees. The fees are structured as a usage-based continuous payment, "based on a contractual percentage of the outstanding principal balance and recognized as revenue as the related mortgage payments are collected" (Cherry Hill Mortgage Investment Corporation, 2018). The underlying approaches for determining contractual terms were unclear but likely followed a model-based pricing approach. Occasionally, the value may be captured as an instant, single payment from the sale of securities priced at fair value (presumably qualifying as a market- or competition-based pricing strategy) for portfolio management. Under a joint sub-servicing agreement, Aurora pays Freedom Mortgage loan origination fees, likely in the form of an instant, single payment, for servicing refinanced loans. Freedom Mortgage was authorized to sell the loan and transfer MSRs to Aurora. This agreement assumed that Freedom Mortgage captured value at a minimum from mortgage origination, servicing, and loan sales. The specific approach to capture value was unclear.

Freedom Mortgage promptly delivered value through direct, high engagement from loan specialists; and direct, low engagement through their official website. Freedom Mortgage concentrates its offering of the economic value of a financial asset and the functional value of purchasing a home to a need-based customer segment - U.S. homebuyers and borrowers. Cherry Hill offered functional value to job-based segments – Freedom Mortgage and other mortgage lenders and counterparties for repurchase agreements. Freedom Mortgage promotes direct, pull strategies such as purchasing incentives and coupons (e.g., close on-time guarantee or low rate guarantee) to convey their value and convert consumers to purchase. Aurora has three sub-servicing agreements, which were a legal means to prevent disturbance to their intangible asset value creation. Forward-setting purchases of RMBS were a legal means to avert interruptions to the financial asset value creation.

Cherry Hill competes as an analyzer differentiating itself by pursuing scrupulous investments in GSE risk-sharing securities and creating intercompany MSRs. Freedom Mortgage competes as a defender aiming to compete on measures of customer experience and agility. Their emphasis on customer satisfaction is evident by their close on-time guarantee subsidy, highlighting their agility and the low-rate guarantee.

Cherry Hill's strategic management of borrowing capital was a crucial component of its overall value management strategy. First, a significant portion of equity capital is utilized to acquire Servicing Related Assets through bulk and flow purchases (Cherry Hill Mortgage Investment Corporation, 2018). Second, the Company's mortgage servicing Aurora acquired Excess MSRs to develop intercompany Excess MSRs (Cherry Hill Mortgage Investment

Corporation, 2018). Third, the Company obtained RMBS on a leveraged basis through repurchase transactions under master repurchase agreements. Repurchase transactions are treated as collateralized financing transactions and are carried at their contractual amounts as specified in the respective transactions (Cherry Hill Mortgage Investment Corporation, 2018). Last, the Company applies hedging instruments and recapture agreements to "opportunistically" mitigates prepayment, interest rate, and credit risk (Cherry Hill Mortgage Investment Corporation, 2018).

Cherry Hill built capital from operating activities such as:

"*1) investments in RMBS, 2) net servicing income from our MSRs, 3) sales or repayments of RMBS, 4) borrowings under repurchase agreements, 5) our MSR financing arrangements*" (Cherry Hill Mortgage Investment Corporation, 2018). The Company's borrowings under repurchase agreements were primarily due to the investment of funds in Agency RMBS received from amounts borrowed under the MSR Financing Facility and the MSR Term Facility (Cherry Hill Mortgage Investment Corporation, 2018).

Howard Hughes

The Howard Hughes Corporation was likely taxed as a C-Corporation in Texas, presumably with a divisional structure of four operating business segments: Operating Assets; MPCs; Seaport District, and Strategic Developments. The Company is not taxed as a REIT; therefore, "are not required to pay dividends, and are not restricted from investing in any asset type, amenity or service, providing further flexibility as compared to many other real estate companies" (The Howard Hughes Corporation, 2020). In the remainder of the text, the Howard Hughes Corporation may be referred to as "Howard Hughes" or "HHC," their trading symbol.

Howard Hughes creates value from four business segments: 1) Operating Assets, 2) Master Planned Communities (MPCs), 3) Seaport District, 4) Strategic Developments. HHC manufactured and added value to physical assets through property development and redevelopment of condominium and commercial developments. Value was added to physical assets in the form of property redevelopment ranging from partial to full demolition of existing structures for new construction. The MPC segment added value through residential and commercial land development, including horizontal land development. HHC lent physical assets for multifamily leasing, retail, office, self-storage, hospitality (lodging), and space for advertising and sponsorship. HHC manufactured hospitality services (food and beverage) and ground maintenance. Similarly, HHC designed services through homeowner association management and distributed cable and internet services.

At closing, revenue from selling an individual condominium unit was recognized, indicative of a value-based pricing, instant single payment structure. MPC land sales captured value as an adder of value to physical assets. This revenue was recognized at closing (indicative of an instant, single payment), and pricing had a fixed and variable component. The fixed transaction price for the improved land was recorded using the cost input method, suggesting a cost-based pricing method. The Building Participation Price was the variable pricing component dependent on a predetermined percentage of the excess income over a developer's breakpoint when a home is sold to a homebuyer; this suggests value-based pricing.

Value is captured from lending physical assets using rent - minimum rent, percentage rent, and overage rent - and tenant recoveries. The leasing models follow model-based pricing methods and differ by collectability. Minimum rent is recognized on a straight-line basis, indicative of a subscription time-based, at the agreed-upon lease terms when the tenant takes possession of the leased asset. In lieu of minimum rent, a percentage rent strategy may be employed and recognized when tenant sales are reported. This structure contained a pre-determined percentage, likely of tenant sales, indicative of subscription, volume-based model. When tenant sales exceed a minimum contractual amount, then overage rent is realized on an accrual basis. The overage rent was calculated by multiplying the excess of tenant sales with a predetermined percentage; indicative of a subscription, volume-based model. Tenant recoveries are priced based on various factors (model-based pricing) and recognized during the period the costs are incurred (likely following a subscription-time-based model). Hospitality revenue was captured from lodging (lending spaces) and (food and beverage services) manufacturing services. The pricing of the hospitality offerings was fixed and likely cost-based. The lodging revenue follows a time-based subscription because it was recognized in daily increments. The food and beverage revenue was recognized at the point of sale or as an instant single payment structure. HHC recognized the following revenue streams as other land revenue. Revenues from the cable and internet service, homeowner association management fee, and ground maintenance are recognized as land revenue generated at fixed prices recognized over time, illustrative of a subscription time-based payment structure, likely priced based on costs. Revenues from the forfeiture of condominium earnest money deposits, the secondary sales of homes in MPCs, and other miscellaneous items were recognized at a legal point in time demonstrative of an instant single payment structure priced likely based on value, but the pricing method was uncertain. Additional rental and property revenue were generated from events-related service revenue-retail operations, baseball-related ticket sales, food sales - and advertising and sponsorships. The transaction price for events-related services was fixed. The total net sales from retail operations and single baseball tickets are recognized at the time of sale that is exemplary of an instant single payment structure. The season ticket revenue is recognized over time as games occur like a time-based subscription payment structure. Revenue from baseball-related and other sponsorships were typically generated over a season or specified duration documented on a straight-line basis, indicative of a time-based subscription payment structure unless the contract stipulates point-in-time delivery. Revenue from third-party advertisements and sponsorship at HHC venues for a contractual duration is generated at fixed prices and recognized on a straight-line basis over time, telling of a time-based subscription payment structure. The pricing methods for the additional rental and property revenue were unclear.

HHC delivers value using direct high engagement approaches with condominium purchasing agreement signings and events-related services. Also, HHC has an official website for direct, low engagement with customers. HHC used broadcasts and direct mail advertisements as indirect and direct push strategies, respectively, to acquire and convert customers. Special events are a direct pull promotion of value. Online digital and social media programs also were employed by HHC either as a direct push promotion or an indirect pull advertisement tactic.

HHC offered the experiential value of places to work and shop for specific psychographic groups in cities (e.g., Seaport District). HHC offers functional value to need and job-based customer segments. Need-based segments include third-party companies seeking advertisement space, condominium buyers/home owners, event attendees, and retail customers. Job-based groups include third-party companies seeking event space, residential homebuilders and developers, and non-competing land users (e.g., hospitals) receiving the functional value of an event venue or land, respectively.

HHC used partnerships and joint ventures to develop and operate its real estate assets, preventing disruption to their physical asset value creation. HHC's evaluation of their builder participation price contracts at each reporting period and market studies anticipate any disturbances to their financial assets value creation. HHC maintains a diverse portfolio to prevent value disturbances to financial assets. HHC keeps a low leverage balance sheet, uses non-recourse debt for construction financing, long-term fixed-rate mortgage financing, limited cross-collateralization for construction financing, and credit facilities to recover from financial asset losses.

HHC generally acted as a defender and a prospector, and to a lesser extent an analyzer, to maintain its competitive advantage. HHC competed on stability, efficiency, differentiation, quality, experience, agility, and reach dimensions. Achieving scale, substantial financial flexibility, long-term contracts, and development pipelines illustrated the organization's stability skill. HHC's pricing power in lease and vendor negotiations, the operational efficiency of management teams, substantial operating flexibility through redevelopment or repositioning, and cost controlling skills of MPCs were indicators of HHC's competitive advantage of efficiency as defending competitors. Their land development and planning expertise and large-scale, long-range development acumen were indicative of a prospector competitor scoping for new measures to achieve efficiency. HHC differentiates themselves from their competition in their ability to largely self-fund new development projects without property dispositions or raising other equity. Also, the cyclical value created from their operational synergies was a differentiating competitive advantage that a protective competitor could leverage. Design excellence and community awards for their MPCs exhibited their advantage on product quality. HHC aims to meet changing customer needs and create value in desirable locations. These points were suggestive of HHC's goal to provide a good customer experience to compete as defenders and analyzers. Their flexibility to meet varying customer needs and their strength to identify and benefit from emerging opportunities exemplified a prospector's advantage of agility. HHC's reach was another advantage. An example of the reach is the MPCs are in high-demand geographic areas, covering over 80K gross acres with 6.6K residential acres of land and 3.4K acres for commercial development " (The Howard Hughes Corporation, 2020).

Howard Hughes "buys" local talent to build their leadership and leasing teams. HHC's value management through their facilities was critical to their business strategy; "the operational synergies of the Operating Assets, MPC, and Strategic Developments create a unique and continuous value-creation cycle." In the MPCs segment, stable strategic developments were transitioned into their Operating Assets segment to increase the recurring Net Operating Income and fund the equity requirements in Strategic Developments. HHC owned "one of the preeminent development pipelines in the world with over 50.0 million square feet of vertical entitlements" (The Howard Hughes Corporation, 2020) without acquiring another development site or external asset, providing a perceived "significant competitive advantage over other real estate development corporations" (The Howard Hughes Corporation, 2020). Their MPC segment retains 80,000 gross acres, including approximately 9,943 saleable acres of land, 6,600 residential acres of undeveloped land for sale, and 3,400 acres designated for commercial development or sale in high-demand geographic areas (The Howard Hughes Corporation, 2020). Residential sales "generated from finished lot sales and undeveloped super pads to residential homebuilders and developers included standard and custom parcels designated for detached and attached single-family homes, and range from entry-level to luxury homes" (The Howard Hughes Corporation, 2020). New homeowners have increased demand for commercial offerings such as retail, office, self-storage, and hospitality facilities. In alignment with the previous strategy, the MPCs segment owned "72 assets, including investments in joint ventures and other assets, consisting of 14 retail, 32 office, nine multi-family, three hospitality properties, and 13 other operating assets and investments" and the Strategic Developments segment held "21 development or redevelopment projects, excluding the Seaport District" (The Howard Hughes Corporation, 2020). The Operating Asset segment will sell an asset when it no longer meets its strategic goals or complements existing properties. HHC owned approximately 9.0 million square feet of retail and office space, 2,909 multi-family units, and 909 rooms in hospitality assets, excluding projects under construction. Their assets were located across diverse markets in nine states in the United States.

The Company manages capital to "provided significant financial and operating flexibility" with the goal of "maximizing the real estate portfolio value." The MPCs segment maintains a "low leverage and flexible balance sheet." This Company "obtained non-recourse debt for construction and long-term fixed-rate mortgage financing" and "limited cross-collateralization for construction financing." Low leverage, project-specific financing minimizes potential losses during economic downturns and financial flexibility to evaluate new project opportunities. The Strategic Developments segments obtained construction financing to fund most of the development costs. The MPCs segment operates on a "self-funded business plan" as the Company "self-funds significant portions of new developments" in place of acquiring capital from "completed development dispositions or raising additional equity." The equity required to execute many development opportunities is funded from the free cash flow created from residential land sales, recurring NOI, and profits from condominium unit sales. Capital gains in the MPCs segment are from "planning, developing and managing small cities in markets with strong long-term growth fundamentals" (The Howard Hughes Corporation, 2020), considering it can take up to three years from the sale of land to a developer to close on a completed home.

Vornado

Vornado Realty Trust is a fully-integrated REIT taxed in Maryland, and Vornado Realty L.P., a Delaware limited partnership referred to as the "Operating Partnership." The Operating Partnership was "the entity through which we conduct substantially all of our business and own, either directly or through subsidiaries, substantially all of our assets" (Vornado Realty Trust and Vornado Realty L.P., 2019). Vornado Realty Trust and Vornado Realty L.P. will be abbreviated as Vornado for the remainder of the text. Vornado manufactured physical assets in the form of commercial and residential property development. Vornado lent physical assets (e.g., commercial space) and added value to physical assets by redeveloping commercial properties. Also, Vornado lent financial assets through the agency of investing in operating companies with real estate components and select properties. Lastly, Vornado manufactured building maintenance, management, and leasing services.

Vornado primarily captures value from property rental income as it is their primary source of cash flow. Complementary to base rent revenue, Vornado recognizes revenue from trade shows, hotels, tenant recoveries, tenant services, building maintenance, management, and leasing services. However, asset sales proceeds from debt financings and proceeds from the issuance of common and preferred equity securities are other sources of liquidity. Property rental income follows a value-based pricing, time-based subscription model because rents are recognized on a straight-line basis, and an internal pricing model was not mentioned. It was assumed that asset sales, including condominium sales, were priced based on value and received as an instant, single payment at the time of sale. Room, food and beverage, and banquet revenue generate the total hotel revenue. Food, beverage, and banquet revenue is recognized as services are given (Vornado Realty Trust and Vornado Realty L.P., 2019). Room revenue is recognized as rooms are occupied (Vornado Realty Trust and Vornado Realty L.P., 2019). Trade shows revenue is mainly booth revenue (Vornado Realty Trust and Vornado Realty L.P., 2019). Inferences can be made regarding the hotel and trade shows revenue stream but was unrelated to residential buildings and outside the scope of this work.

Tenant recoveries were recognized during the period in which they occur. Assuming tenant recoveries follow model-based pricing, the payment structure was unknown. Tenant services revenue was generated from sub-metered electric, elevator, trash removal, and other services. The pricing model and payment structure to capture value from tenant services were undetermined. Building management, leasing, and maintenance (e.g., cleaning, engineering, and security) services were captured as fees. This income was recognized either on a straight-line basis (time-based, subscription model) or when a tenant vacated (instant, single payment) and was likely priced based on costs.

Vornado primarily offered functional value and secondarily provided experiential value for customers connected by job group (i.e., commercial tenants and customers) and identified by need (i.e., home buyers and renters). Vornado used a comfortable, direct high-engagement approach with leasing agents who deliver value to current or potential tenants. Similarly, their official website to request building services was a comfortable, direct low-engagement approach to deliver value to tenants.

Joint development and redevelopment ventures anticipate value disturbances to physical assets. Unsecured revolving credit facilities and secured debt sources to recover financial losses. Vornado sustained "a superior team of operating and investment professionals and an entrepreneurial spirit" (Vornado Realty Trust and Vornado Realty L.P., 2019) to anticipate value disturbances through their human assets. Vornado's strategy to sustain value or its competitive advantage was not evident.

Vornado Realty Trust was the sole general partner and a 93.4% limited partner of the Operating Partnership (Vornado Realty Trust and Vornado Realty L.P., 2019). Vornado "has exclusive control of the Operating Partnership's day-to-day management, and conducts its business through, and substantially all of its interests in properties are held by, the Operating Partnership" (Vornado Realty Trust and Vornado Realty L.P., 2019). and Vornado Realty L.P., Vornado provides cleaning, security, and engineering services primarily to owned NY properties through Building Maintenance Service LLC. Vornado's management organization structure was centralized mainly in New York City with employees and properties such as Hotel Pennsylvania and theMART. For example, "VNO's portfolio is concentrated on premier Office and high Street Retail properties in New York City which has a long history of strong real estate fundamentals" (Vornado Realty Trust and Vornado Realty L.P., 2019).

The Company built and bought facilities. Vornado strategically acquired quality properties in areas with increased potential for higher rent at a discount to replacement cost and developed and redeveloped existing properties to boost returns and maximize value. Their collection of assets were focused “to help shape the way Americans live, work, play, and shop.”

Vornado’s capital is invested in properties in select markets with a high likelihood of capital appreciation, retail properties in select under-stored locations, and operating companies with a notable real estate component. Vornado borrows money to increase capital through “include proceeds from debt financings, including mortgage loans, senior unsecured borrowings, unsecured term loan, and unsecured revolving credit facilities” (Vornado Realty Trust and Vornado Realty L.P., 2019). Also, the Company gains capital from “proceeds from the issuance of common and preferred equity securities; and asset sales” (Vornado Realty Trust and Vornado Realty L.P., 2019).

Welltower

Welltower Inc. was likely taxed as a Delaware C-Corporation with principal executive offices in Ohio. Their organizational structure is likely divisional as the “internal property management division manages and monitors the outpatient medical portfolio” (Welltower Inc., 2020). Welltower Inc. will be referred to as Welltower in the remaining text. Welltower reports their business in three segments: 1) Seniors Housing Operating segment, 2) Outpatient Medical segment, and 3) Triple-net segment. Welltower lends physical assets that are multi-tenant properties (e.g., outpatient medical portfolio, senior housing operating/ triple-net properties). At these properties, Welltower manufactures and aggregates services. In the Outpatient Medical segment, property management services are manufactured. The Seniors Housing Operating segment manufactured asset and property management, leasing, marketing, and other services. Services are aggregated at properties in the Senior Housing Operating and Triple-net properties segments. Welltower also lent financial assets by investing in senior housing and health care real estate. They invest in the form of construction loans, real estate loans (e.g., mortgage loans), and non real estate loans (e.g., corporate loans with no real estate backing).

Welltower captured value from lending physical assets as rental income, manufacturing and aggregating services as fees, and lending financial assets as interest income. Gains and losses from the disposition of real estate are also recorded. Rental income is the primary source of revenue for the Triple-net and Outpatient Medical segments. Leasing arrangements included fixed annual rental escalators recognized on a straight-line basis and contingent rental escalators recognized on a contractual period term; both stipulations suggested time-based subscription payment structures priced based on value. The exceptions were payments for Medicaid beneficiaries at Triple-net properties follow market-based pricing at a fixed daily rate. Welltower receives Medicare reimbursements for Medicare-funded residents at Triple-net properties on a physician fee schedule or Hospital Outpatient Department's or Ambulatory Surgical Centers' prospective payment systems (pay-for-quality model); representing a market-priced, delayed, single payment structure. Also, Outpatient Medical agreements may include operating reimbursements from the tenant. Fees from the services offered in the Seniors Housing Operating segment were its primary revenue source. These fees were often cancellable, recognized monthly for one-year terms, exemplary of a time-based subscription model. The payment plans were likely priced based on value, except for Medicare beneficiary payments priced based on the market. Resident payment plans may include entrance fees (assumed to be instant, single payments), condominium fees, rental fees, or monthly maintenance fees in exchange for a living unit, meals, and some health services. Senior Housing Operating segment care homes' receive a daily rate or rent. Loan interest income is recognized when earned as a function of the outstanding principal amount following a usage-based continuous payment. Value is captured from the interest income, principal amortization, and transaction fees associated with real estate loans. It is assumed the terms of these loans are based on an internal model, and therefore, the pricing was model-based. Gains from real estate dispositions are likely priced based on value and were recognized at a point in time when recognition criteria (e.g., when the title was transferred) have been met which was typical of an instant, single payment. A project's residual profits generated through the sale, refinancing, or acquisition of the property were likely based on the value-based pricing of the asset. Welltower has leasing arrangements with purchase options that qualify under this method of value capture.

Overall, Welltower offered functional value for the aging global demographic. The Senior Housing Operating provides functional value for the older adults (i.e., usually aged 55 years or older) able to care for themselves demographic for their senior apartments. The Senior Housing Operating and Triple-net properties segments provide experiential value to demographic and psychographic groups. For example, care homes attract seniors in the U.K. who need nursing but do not need post-acute care. Another demographic are senior Canadian residents preferring access to meals and other services such as housekeeping, linen service, transportation, and social and recreational activities for independent living and independent supportive living residences. Two psychographic groups were seniors needing assistance with daily living activities that preserve a person's mobility and social systems to promote cognitive engagement, 24-hour nursing, medical or health care, and patients seeking post-acute care (often requiring 24-hour nursing or medical care). Third parties in need of loans for acquiring, developing, and constructing in-substance real estate were a need-based segment receiving a functional benefit from Welltower investments. Also, patients were a need-based group receiving a functional benefit in the Outpatient Medical business. The following job-based customer segments were beneficiaries of the functional value provided by Welltower. Health care providers and outpatient medical centers were job-based recipients of the functional value provided by Welltower's investments. The Outpatient Medical business enabled the functional value of health care provider connectivity in local markets to health systems. The Senior Housing Operating segment offered functional value to private pay sources, U.S. federal and state governments (i.e., Medicaid and Medicare regulators), and housing operators. Triple-net properties targeted U.S. federal and state governments (i.e., Medicaid and Medicare regulators), physicians, hospital outpatient departments, and ambulatory surgical centers.

Service contracts, joint ventures, and partnerships are agreements employed throughout the company to protect the value created by physical assets. For example, the Senior Housing Operating segment partnered with service operators. Also, management contracts as part of joint venture agreements "provide asset and property management, leasing, marketing, and other services" (Welltower Inc., 2020). In-house property management division was an organizational means to anticipate issues to Outpatient Medical physical asset value creation. Studies of the economic environment and market are strategies to preclude interruption to financial asset value creation. Diversification is a financial tactic employed to prevent value disturbances. No single tenant contributes more than 20% of their revenue indicative of their revenue source diversification to avoid value disruptions. Their investment portfolio is spread across property types, relationships, and geographic locations. Credit enhancements during the construction process and outpatient medical leases enabled Welltower to absorb construction and operation financial disturbances. The use of multiple business models allows Welltower to absorb disturbances to one form of value creation. Involvement in revolving credit facilities is beneficial to recover from value disturbances financially. Contract agreements with senior housing operators, health systems, and providers were a legal means to secure human assets for value creation.

Welltower is positioned as a defender and an analyzer to maintain its competitive advantage. Long-term operating leases - such as construction leases with a weighted average of 7 years in Outpatient Medical and around 12-15 years for Triple-net properties - were examples of the Company's stability. Their assembly of partners across the care continuum is indicative of the customer relationship strength (stability) and ability to achieve efficiency. Cost control and operational efficiency are defending competitor goals attained through their property management division. This division "manages and monitors the outpatient medical portfolio by optimizing the mix of health service providers, lease expirations, hospital/health system relationships, property performance, capital improvement needs, and market conditions (Welltower Inc., 2020)." As part of their Triple-net properties segment, post-acute care facilities differentiates their services by balancing reduced costs with improved quality, achieving lower hospital readmission rates, and swiftly sending healed patients home. As a REIT, Welltower's investment portfolio diversification criteria are another differentiation technique. Achieving efficiency through the development of high-quality assets was a competitive tactic employed by analyzers. Their state-of-the-art outpatient centers demonstrate this tactic and permit safe and efficient procedures externally to a hospital setting. The outpatient medical centers were accessible, consumer-friendly locations to initiate a good customer experience as an analyzer would. Welltower demonstrated its reach as an analyzer by concentrating its facilities' geographic mix to the U.S. states of California, Texas, and New Jersey, the U.K., and Canada.

The Company borrowed talent by relying on partnerships "to effectively and efficiently manage their properties." For example, operators enter incentive-based management contracts to provide property management services to the seniors housing operating properties.
Welltower capital was allocated to "investments in senior housing and health care real estate through acquisitions, developments, and joint venture partnerships"; therefore, Welltower bought and built facilities. Their investment portfolio was diversified in terms of property type, relationship, and geographic location.

The Company borrowed and built capital to fund investments using a mix of debt and equity, as stated below (Welltower Inc., 2020):

"*Generally, we intend to issue unsecured, fixed-rate public debt with long-term maturities to approximate the maturities on our triple-net leases and investment strategy. For short-term purposes, we may borrow on our primary unsecured credit facility or issue commercial paper. We replace these borrowings with long-term capital such as senior unsecured notes or common stock. When terms are deemed favorable, we may invest in properties subject to existing mortgage indebtedness. In addition, we may obtain secured financing for unleveraged properties in which we have invested or may refinance properties acquired on a leveraged basis. In certain agreements with our lenders, we are subject to restrictions with respect to secured and unsecured indebtedness.*"

Capital and talent management were critical to their management of value because the two are intertwined in their investment criteria (Welltower Inc., 2020):

> "In determining whether to invest in a property, we focus on the following: (1) the experience of the obligor's/partner's management team; (2) the historical and projected financial and operational performance of the property; (3) the credit of the obligor/partner; (4) the security for any lease or loan; (5) the real estate attributes of the building and its location; (6) the capital committed to the property by the obligor/partner; and (7) the operating fundamentals of the applicable industry."

Different methods are utilized to monitor their investments by property type. For example,

> "the asset management process for seniors housing properties generally includes a review of monthly financial statements and other operating data for each property, review of obligor/partner creditworthiness, property inspections, and review of covenant compliance relating to licensure, real estate taxes, letters of credit and other collateral."

Welltower's real property was land, buildings, improvements, and related rights. The outpatient medical portfolio is comprised of multi-tenant properties leased to health care providers and was primarily self-managed. State-of-the-art outpatient centers in accessible, consumer-friendly locations were important characteristics of their outpatient medical building portfolio, including physician offices, ambulatory surgery centers, diagnostic facilities, outpatient services, and labs (Welltower Inc., 2020). Welltower's portfolio of outpatient medical buildings was an integral part of producing health care provider connectivity in local markets. Separately, approximately 95% of triple-net properties were subject to master leases, and tenants are required to repair, rebuild and maintain the leased properties (Welltower Inc., 2020). Most of the triple-net properties operating leases were designed with escalating rent structures, and some contain purchase options. Welltower may offer property management, leasing, marketing, and other services as part of their senior housing facilities. A comprehensive review of their portfolio often includes "tenant relations, lease expirations, the mix of health service providers, hospital/health system relationships, property performance, capital improvement needs, and market conditions" (Welltower Inc., 2020).

Jones Lang LaSalle

Jones Lang LaSalle Incorporated is a Maryland corporation and is likely taxed as a C-Corporation. Jones Lang LaSalle Incorporated may be referenced as its trading symbol "JLL" in the remaining text.

JLL earned revenue from six different business segments and across various asset types. For simplicity, how each segment creates, captures, and identifies value are conjointly discussed. Overall, JLL offered functional value across job and need groups, such as real estate owners, occupiers, and investors globally and across industries ranging from for-profit ad not-for-profit entities, public-private partnerships, and governmental entities. Concurrently, JLL aimed to provide experiential value to large organizations.

First was JLL's Leasing segment, where JLL manufactured agency leasing and tenant representation services. These services include defining space requirements, identifying suitable alternatives, recommending appropriate occupancy solutions, negotiating lease and ownership terms with landlords, and executing transactions for occupier clients to meet their occupancy requirements and ongoing real estate needs. Tenant representation may also qualify JLL as a broker of physical assets. Earned leasing revenue, brokerage commissions, were assumed to be single payments, recognized instantly at the lease execution. These fees were priced based on value, either as a percentage of the executed lease revenue commitment value or the monetary amount per square foot leased. This segment provided functional value to need-based clients; property owners (e.g., investors, developers, property companies, and public entities).

The second was JLL's Capital Markets segment which lent financial assets and manufactured and added services. JLL lent financial assets as a commercial multifamily lender and loan servicer. This segment manufactured investment banking services, sales and acquisitions, debt placement, equity placement, financing arrangement, and corporate finance services. Also, their funds advisory service, M&A, and corporate advisory service positioned them as an adder of services. The pricing of the Capital Markets segment's income-generating activities is derived from the value of the transactions making it value-based pricing. Except for loan servicing income, value was captured as instant, single payment fees for each value creation activity. First, loan origination fees are collected from commercial loan servicing activities (lending of financial assets). Commercial loan servicing income was likely a continuous payment based on the usage (i.e., a percentage of the borrowed amount). Second, transaction fees are recognized at the satisfactory execution of capital transactions (manufacturing of services). Last, retainer fees received are for portfolio advisory services (adding to services). This segment provided functional and economic value for job groups (i.e., all types of lenders); the equity placement and funds advisory clientele were public and private real estate companies, including institutional advisors.

The third was their Property & Facility Management segment. This segment creates value from managing and outsourcing properties and real estate portfolios with on-site, full-service integrated facilities management and property management services for office, industrial, multifamily residential, and specialty properties (manufacturer of services) (Jones Lang LaSalle Incorporated, 2020). In some cases, JLL acts as an agent for Facility and Property Management clients concerning third-party vendors and subcontractors engaged in delivering operational services to client properties. In these cases, JLL creates value as an aggregator of services. Some management agreements have performance-based incentives related to financial and human outcomes (i.e., financial and operational results, end-user experience, client satisfaction), indicating this segment created value as a manufacturer of outcomes. Property management revenue is collected for services delivered over time (1-3 years contract terms) as a monthly management fee, suggesting a time-based subscription model. The fee is priced as a function of cash receipts, the managed square foot, or other variable metrics exhibit model-based pricing. Some management agreements have a performance-based incentive based on lowered expenses, tenant satisfaction, gross revenue, or occupancy goals. This income was exhibitive of value-based pricing, likely following the same payment schedule. The property management fees are likely priced based on costs, but the payment structure was unclear but likely were continuous payments based on usage in instances where costs are incurred on the client's behalf. The facilities management revenue was captured through cost reimbursement, management fees, and often, incentive fees or other forms of variable metrics. Daily performance obligations delivered over time under management agreements ranging from 3-7 years. The management fees were assumed to be base (fixed) fees for daily services provided over time, indicative of a time-based subscription model. Pricing was structured to include cost reimbursement plus a base fee; therefore, this subscription model is likely priced relative to costs, but the pricing method was unclear. The cost reimbursement revenue payments were likely structured as continuous payments based on usage and priced-based costs, but the payment structure was ambiguous. The incentive fee was a performance-based component priced based on value (i.e., client satisfaction survey results and other quantitative performance measures). The incentive fee payments likely follow the overall contract payment structure. This segment offers value to populations segmented by job and need groups. Economic and functional value was presented to corporations and institutions (job group), and experiential value to clients' tenants (need group).

The Project & Development Services segment provided consulting (lends human assets), design (designs physical assets), management (aggregates and designs services), and build (manufactures physical assets). As a designer of physical assets, this segment designs and manages real estate projects, including fit-out services through design, fit-out, and refurbishment services. In their consulting, design, management, and build services. This segment also provided short-term construction-related services ranging from general contracting (aggregator of services) to project management (designer of services) for owners and occupiers of real estate. When assuming responsibility for completing a project, JLL creates value as a physical asset manufacturer. Value from the Project & Development Services segment was captured in negotiated fees with a possible cost reimbursement component. Revenue is recognized over time, typically using input measures such as to-date costs. The fees structure indicates a value-priced, usage-based continuous payment model. The cost reimbursement model marked a cost-priced, continuous payment structure based on usage. Contract lengths are typically less than one year but may be extended. This segment provides functional value to need-based clients; leased space tenants, self-occupied building owners, and real estate investment owners from public entities and educational institutions primarily in the U.S.

The Advisory, Consulting, and Other business acted as an adder of services and lender of human assets through their advisory and consulting services. These services included value-added real estate consulting services in such areas as technology implementation and optimization, mergers and acquisitions, asset management, occupier portfolio strategy, workplace solutions, location advisory, industry research, financial optimization strategies, organizational strategy, and

Six Sigma process solutions. This segment manufactured energy and sustainability services. Also, this segment designs financial services, including acquisitions, dispositions, debt and equity financings, mergers and acquisitions, securities offerings (including initial public offerings), and privatization initiatives. The Advisory, Consulting, and Other segment was paid as fees. Advisory, consulting, and valuation services received negotiated fees based on the agreed work plan and asset value, suggesting value-based pricing. Similarly, the energy and sustainability services area employed several compensation models, which may be shared savings or fees for service, which are likely also value-based. In this business segment, most services were delivered over time following a usage-based, continuous payment structure. Other arrangements may be event-driven point-in-time transactions, which may characterize as delayed, single payment structures. This segment offers economic and experiential value to populations segmented by need group. Public and private sector commercial real estate property owners, investors, and financing sources are provided the former, and occupiers the latter.

LaSalle lends financial assets through global indirect investments, primarily in private equity funds, joint ventures, and co-investments, as well as publicly-traded real estate investment trusts ("REITs") and other real estate equities; manufactures financial services through real estate investment management; acquisition, financing, leasing, management, and divestiture of real estate investments; and is an adder of services delivering advisory services. The LaSalle business segment captures value in advisory fees, incentive fees, and transaction fees. The advisory and incentive fees depend on the investment performance, indicative of value-based pricing. Transaction fees are collected for acquisitions, financings, and dispositions and may be a function of the managed assets market value (also suggestive of value-based pricing). Transaction and incentive fees are generally constrained until all contingencies are cleared, indicative of delayed, single payments. LaSalle typically manages client’s investment portfolios for five to nine years, or under an open-ended contract, with daily performance obligations. These fees likely follow a usage-based, continuous payment structure. This segment provides functional value to mature investors (need-based clients).

The Company’s official website supported a direct low-engagement advertisement strategy. The Property & Facility Management segment delivers value using a direct/indirect high-engagement approach focused on elements of accuracy and comfort. Their extended delivery team of in-house personnel (direct) and third-party vendors (indirect) cultivated high levels of tenant satisfaction and occupancy while cutting operating costs. The Advisory, Consulting & Other also focused on delivering value on measures of accuracy and comfort using the direct, low-engagement approach of a digitally-enabled platform for fast and informed decisions. The Advisory, Consulting & Other segment conveyed value using trade advertisements as an indirect push advertisement strategy to gain customer awareness and consideration.

In the Leasing and Property & Facility Management segments, partnerships with clients are an organizational means to anticipate and prevent any values disturbance to physical assets. JLL anticipated value disturbances to intangible assets using research and technological innovation. Their Advisory, Consulting & Other business employed technological innovation through data and technology platforms and solutions. The Capital Markets business researched, developed, and introduced innovative new financial products and strategies. The LaSalle business segment researched capabilities and partnerships. The Project & Development Services uses technology to drive service delivery. The Advisory, Consulting & Other business prevented value disturbances through a global delivery platform which delivered consistent outcomes on a local and global scale. The Capital Markets benefitted from know-how partnerships with public and corporate pension funds, endowments, foundations, banks, insurance companies, advisors, agencies, capital and credit companies, REITs, investment banks, opportunity funds, domestic and foreign banks prevented value disturbances. Service contracts across the various business segments inhibit value shocks as well. The Property & Facility Management limits value disturbances through an extensive global platform with substantial local expertise and digital integrated facility management solutions. The LaSalle segment accessed unsecured credit facilities to absorb and co-invested to anticipate value disarrangements to financial assets. JLL builds expertise to protect value using human assets. The Capital Markets segment had field experts, the LaSalle business segment uses experienced investment professionals, and the Property & Facility Management segment uses local expertise globally. Formal mentoring and coaching programs and knowledge sharing cultivated a high-performing, collaborative, flexible, and inclusive culture. As an example, the Property Management segment centralized resources to share knowledge. This approach prevents and absorbs human asset value disturbances. Human assets received developmental and training opportunities to recover from value disturbance. Multiple business models were intangible assets for JLL to absorb value disturbances to one segment and meet the Company's financial goals.

JLL operated as a defender, a prospector, and an analyzer to control its competitive advantage. The Advisory, Consulting, and Other segment acts as a defender on measures of experience, innovation, reach, and stability; and as a prospector on measures of efficiency to sustain its competitive advantage. On the one hand, the Energy and Sustainability Services group exemplifies a prospector's approach to efficiency in their breadth of technical expertise offered clients end-to-end services, from leasing to capital market transactions and projects to facility management. On the other hand, this business segment acted as defenders. Their global delivery platform delivers reliable results on a local and international scale to serve clients' multi-service, multi-geography needs enabling a positive customer experience through customer service. Their broad geographical coverage is also evidence of their reach. This segment defended its competitive advantage using process innovation, as shown by its digital implementation approaches, digital solutions, and Building Services Network. For example, the Building Services Network unlocks new client segments by transforming end-to-end facility repair and maintenance service delivery. Their Corrigo platform secured the best service providers for clients. The Energy and Sustainability Services group's industrial leadership positions them to realize client's shift to achieve sustainability goals - symptomatic of their stability.

The Capital Markets segment maneuvered as a defender, maintaining their competitive advantage through stability, differentiation, reach, and quality. Their funds advisory group differentiates themselves by effectively completing highly challenging assignments. Also, this group's productive capital raising programs and long-term institutional relationships typify their stability. The Capital Markets segment's reach enables them to serve clients across geographic scales from locally to globally.

JLL sustains value by competing as a defender, an analyzer, and a prospector depending on the segment. As a defender, JLL retained local, regional, and global scale and long-term institutional relationships to protect its stability. The Property & Facility Management segments use a globally integrated platform; digital integrated facility management exemplified a defender's style to deliver operational efficiency to its clients. JLL utilization of technology to administer outstanding service; strong client focus; superior investment performance, occupancy, and tenant satisfaction are evidence of a defender competing on service quality. JLL strove to deliver a premier client experience by tailoring service to individual client needs, creating remarkable spaces and sustainable solutions, and the Property & Facility Management segments aimed to enhance the end-user experience. JLL also strove for fast fulfillment of services. For example, their mobile engineering services provided a single point of contact for services, and their Corrigo platform instantly connects clients to dependable, high-quality services. JLL’s reach is evident in its broad geographic coverage and customer base. They served clients across geographic scales from locally to globally, have important industry contacts, a strong reputation as one of the world's largest institutional capital managers in investment real estate assets and securities. For example, the LaSalle segment operates in 29 countries with geographic distribution across fund types, a global presence, and a coordinated platform. Lastly, JLL defended its competitive advantage using process innovation, as shown by its digital implementation approaches, digital solutions, and innovative investment strategies.

As an analyzer, their broad range of advisory services for considerably all real estate asset classes is distinctive of an analyzer’s differentiation strategy to minimize risk. Their use of technology to generate new opportunities and produce remarkable spaces and sustainable real estate solutions for clients and communities illustrated their ability to adapt to technological changes, symptomatic of an analyzer’s approach to agility.

As a prospector, their real estate investment expertise, digital implementation proficiency, extensive knowledge of commercial real estate, experienced investment professionals, and local market knowledge indicate a prospector’s approach to preserving its efficiency. The Company’s numerous service and product offerings and LaSalle’s research capabilities exemplified a prospector’s form of differentiation.

JLL’s talent was an essential component of its strategic management of value. As such, the company was “committed a high-performance culture”, and “helping their people reach their ambitions by enabling them to explore new opportunities, build expertise, create long-term careers, work with other talented people, and succeed in inclusive, collaborative and flexible working environments” (Jones Lang LaSalle Incorporated, 2020). The Company offered “an array of developmental and training opportunities to support career growth by providing guidance on globally-aligned leadership capabilities and offering formal mentoring and coaching programs” (Jones Lang LaSalle Incorporated, 2020). For example, the Property Management segment offers centralized resources for “training, technical and environmental services, accounting, marketing, and human resources.”

Zillow Group

Zillow Group, Inc. is likely legally structured as C-corporation with a divisional organization structured into three segments: 1) Homes, 2) Internet, Media & Technology ("IMT"), and 3) Mortgages. Zillow Group, Inc. will be referred to as Zillow for the remainder of the text. Zillow's support of property listing positioned the company as a connector of physical assets. Zillow functioned as a connector of financial assets with the mortgage marketplace for purchasing and refinancing opportunities. Zillow connected human assets such as home sellers to local listing agents that advertise on Zillow or local Premier Agent partners, and through the Zillow Rental Network, linking prospective renters with property management and landlord partners. Zillow manufactures title and escrow closing services as part of Zillow Offers. Zillow's Homes segments contained Zillow Offers' home-buying program, where Zillow directly purchased and sold homes. In the cases where no work has been completed on the purchased home, Zillow acted as a distributor of physical assets. Zillow acts as an adder to physical assets when they perform simple, make-ready repairs to resell home. The Homes segment captured value from the instant, single payments of home sales priced based on value. Zillow's IMT segment is a connector of physical assets. Within IMT, the Others segment offers a new construction home marketplace, and the Rentals segment offers advertising products. The Premier Agent advertising products placed the company as an aggregator of physical assets. The IMT segment captures value from the real estate transaction management platform (Dotloop) value-priced monthly (i.e., time-based subscription model). The Mortgages' offerings of mortgage origination, mortgage pre-approvals, and financing through Zillow Home Loans situated the company as a lender of financial assets. Zillow is a connector of human assets through the Mortgages segment's online lender marketplace "Connect." This segment's online customized loan quote and lender marketplace "Custom Quote" placed the company as a services connector. The Mortgages segment captures value from the Connect and Mortech products from monthly fees determined by a model-based pricing standard and time-based subscription model. Mortgage origination fees and prepayment on cost per lead basis for Connect and Custom Quote are determined using model-based pricing captured instantly in single payments. Value is captured as instant, single payment from the sale of mortgages priced at fair value (i.e., market-based pricing). Zillow manufacturers intangible assets across different segments. Their intangible asset offerings include property management services - listings, advertising and leasing, living database of residential homes, complementary rentals marketplace, and rental transaction services platform - pay per lease product and a suite of tools (e.g., rental application platform) in the IMT Rentals segment, brand advertisement display in the IMT Others segment, end-to-end real estate transaction management solution generally in the IMT segment, and mortgage software solutions including a pricing engine and lead management platform in the Mortgages segment. Rental application fees in the Rentals segment were determined using model-based pricing captured instantly in single payments. The Rentals segment receives instant, single payments for their pay per lease advertising model using variable consideration (e.g., model-based pricing model). The Rentals segment also captures value using cost per lead, cost per click, cost per lease, cost per listing or cost per impression basis advertising payment models, or delayed single payment structures priced based on models. The Others segment also captures value using delayed single payment priced based on models such as cost per lead, cost per click, cost per lease, for new construction advertisement payment models, and cost per listing or cost per impression basis for display advertisement payment models. Value from the Premier offerings was seized from a monthly prepaid spend or a usage-based continuous payment which was presumed to be priced using models.

Zillow receives service charges for value-priced, instant, single payments. Zillow employs direct customer engagement strategies for comfortable, accurate, secure, and swift delivery of value. For example, the IMT segment utilized the direct high-touch engagement tactic of phone and email contact to a support team with a comprehensive knowledge base for Dotloop products. Their know-how and service availability of 7 days a week should provide quick and accurate answers. Another direct, high-engagement, speedy delivery of value is used in the Mortgages segment. For example, Zillow sends informative text messages to a group of subscription mortgage professionals, and the first to respond receives consumer contact information. Another example of their direct, high-touch engagement was the value offered by Zillow Offers. Zillow Offers emphasized the comfort of a customer selling their house on their timeline through their four-step process. A Zillow Advisors connects with the customer to answer your questions, provides a Zestimate, schedules a free in-person home condition evaluation, and extends a “no-obligation” cash payment offer. As part of this process, Zillow was responsible for home repairs; the customer selects their closing date and moves out time at their convenience with no buyer negotiations. The Zillow Offers process delivered swift value because the estimated time on the market is shorter.

The Zillow Offers process delivered security because the home was not listed, eliminating the need for open houses.

Low-touch engagement strategies are exhibited throughout the business as well. Zillow often employs direct low engagement strategies. Classic examples of this strategy include Premier Agent solutions and the general Zillow-affiliated mobile applications and websites. Premier Agent Direct offers accuracy as part of their direct, low-touch engagement value delivery to real estate agents through precision targeting home shoppers. Renters benefit from a comfortable, direct, low-touch engagement delivery of value. Zillow platforms provide renters with the "ability to easily submit applications, sign leases and make rental payments" (Zillow Group Inc., 2019). Premier Agent offering delivers speedy, direct, low touch engagement value delivery as Premier Agents can be connected to home shoppers in less than 90 seconds. Similarly, direct, low touch engagement in a comfortable setting was delivered because a buyer can connect with a local real estate professional on Zillow-affiliated mobile applications and websites. Premier Agent delivered direct, low-touch engagement through accurate, actionable client insights, direct messaging with clients for quick responses, and the comfort of exclusive branding. Also, the Premier solutions include "access to a dashboard portal on their mobile application, website, and account management tools, as well as a dynamic share of voice basis in a zip code" (Zillow Group Inc., 2019). The IMT Rentals and Other segment listings are published on their mobile applications and websites. Access to Custom Quote and Zestimate availability on the general Zillow and Mortgages websites were examples of low engagement tactics and showcased their accurate value delivery. Property listing advertisements on Facebook were an indirect, comfortable, low-touch engagement strategy. Dotloop was promoted using the indirect pull approach of trade promotion by offering REALTORS members up to 10 transactions for free. This approach raised real estate agent awareness and nudged them to conversion to purchase Dotloop. Their brand recognition and partnerships referrals were direct and indirect pull promotion strategies to acquire and retain customer attention. Zillow Offers' advisors were a direct push strategy for Homes' customers to receive value. Premier Agent Direct offered the indirect pull strategy of precision targeting advertisements for property listings to remain in consideration of the home shopper purchase funnel. Seller property listings on Zillow and Facebook were advertised to home shoppers after viewing neighborhoods on Zillow-related platforms.

Their “highly experienced management team” was an essential means to anticipate value disturbances. Financial levers available to prevent value creation disturbances included revenue diversification because no customer generated more than 10% of their total revenue, and “convertible senior notes, bi-lateral credit facilities for Zillow Offers, warehouse and repurchase facilities for Zillow Home Loans” (Zillow Group Inc., 2019). On this note, engagement with credit facilities was an organizational financial means to recover in the event of value disruption. “Superior industry partnerships” (Zillow Group Inc., 2019) were an intangible, organizational means to prevent value disruption Zillow. Zillow maintained strong partnerships with real estate agents, brokers, mortgage professionals, property managers, landlords, home builders, and regional multiple listing services (Zillow Group Inc., 2019). Patented proprietary automated valuation models like Zestimate, and trademarked Dotloop were legal, intangible assets to prevent value disruption.

Zillow targeted need-based and job-based customer segments. On the former, they provided functional value to homebuyers, emotional value during a stressful period to the population changing residences, economic and experiential value to borrowers and home sellers. On the latter, they provided functional, social, and experiential value to real estate agents. Their Mortgages segment gave functional value to borrowers (need-based customer group), mortgage lenders and other mortgage professionals, secondary mortgage market (job-based customers). The Others segment within IMT supported the need-based group of home shoppers. The IMT segment contributes functional value to job-based groups, businesses, and professionals associated with residential real estate and rental industries (i.e., real estate and rental professionals and brand advertisers, brokerages, real estate agents, REALTORS members). Similarly, the Rentals segment within IMT supplied rental professionals, landlords, property managers, and other market participants. Also, the Others segment within IMT supports home builders and advertisers.

Zillow primarily competed as a prospector but contextually leveraged defender capabilities. Zillow’s advantages as a defender were evident in their strategies to achieve reach, experience, differentiation, and stability. Zillow was a popular and trusted brand with a large and engaged audience to match. The Company claimed “Zillow” was searched more often than "real estate” and attracted 200M unique users in July 2019 with more than 8B visits” (Zillow Group Inc., 2019)”. They maintained the largest collection of U.S. rental properties, and Zillow Home Loans is available in 44 states. their “seasoned management team works to deliver a seamless real estate transaction experience for customers" (Zillow Group Inc., 2019), and their Premier Agent Direct offers "effortless advertisement setup" (Zillow Group Inc., 2019) like a defender competing to offered a high-quality customer experience. They offered premium exposure for listings as a key differentiating factor only a defender could provide. Their defender-like competitive advantage of stability was evident in their customer relationship strength (e.g., 200M unique users acquired in July 2019), notable industry partnerships, and "strong balance sheet."

Zillow competed as a prospector on innovation, efficiency, stability, differentiation, and experience. Zillow innovated their products, not processes, like a prospector to deliver a "fully integrated home shopping experience" (Zillow Group Inc., 2019). Their products were a process innovation, offering a "streamlined version of the traditional home-selling transaction." For example, Zillow Offers enabled a "hassle-free way" to buy and sell eligible homes directly. Their technical expertise in building transaction-focused real estate, mortgage, and e-commerce businesses and sophisticated capital market financing marked a prospector's tactic to efficiency. Dotloop was the "only all-in-one real estate transaction management software on the market," evidence of their patent position/exclusivity, a strategy of stability seized by a prospector. Their original product offerings – the unparalleled database of 100M+ U.S. homes, home valuation technologies (e.g., Zestimate and Zillow Offers pricing algorithm), and secured integrated real estate transaction platform – offered real estate transaction transparency, control to consumers, and displayed a prospector's approach to differentiation. Prospectors extend a high-quality customer experience through easy-to-use or customizable products. Correspondingly, their IMT segment offered individualized program performance analytics, custom branding features, and a customer relationship management tool for users, and the Mortgages segment supplied custom mortgage loan quotes.

Zillow built intellectual property, bought, and borrowed talent, and borrowed capital.

Zillow built intellectual property through ZapLabs. Zillow bought talent to ensure an "experienced, proven management team of executive talent with deep experience in building transaction-focused real estate, mortgage, and e-commerce businesses as well as sophisticated capital market financing" (Zillow Group Inc., 2019). Generally, Zillow prided itself on developing and maintaining industry partnerships. Zillow Offers was an example of how the Company borrowed talent to manage value. Zillow leverage partner agents and brokers on the buy and sell side to represent them in a Zillow-owned home transaction. Regarding acquiring capital, Zillow claimed to have “a strong balance sheet, a large and growing IMT business that generates substantial cash flow to help finance the expansion of our new businesses, and access to multiple sources of capital to fund investments” (Zillow Group Inc., 2019).