Critique of and System Design for Optimization in Construction Supply Chain Management with Consideration for the SEAD Village

Alec Zhou

Electrical Engineering and Computer Sciences
University of California, Berkeley

Technical Report No. UCB/EECS-2022-78
http://www2.eecs.berkeley.edu/Pubs/TechRpts/2022/EECS-2022-78.html

May 12, 2022

Acknowledgement

Thanks to Somayeh Sojoudi for teaching me optimization theory, Khalid Mosalam for being a steadfast advocate for our Solar Decathlon team, Scott Moura for providing his class to develop our IoT system, and Iris Tommelein for teaching me about construction supply chains. Additional thanks to Seth Wachtel, Sally Hindman, Reginald Gentry and the youth at YSA, especially Brandon Harris and Ana Caroline, for keeping me focused on the fight against houselessness. My deepest appreciation to all of my friends and teammates in SHAC for their inspirational enthusiasm for equitable housing, especially Mia Campbell. All my love to Sage Quinn for her unwavering love and support as the best partner I could imagine. To my parents and sister, thank you for making me the person I am today.

Critique of and System Design for Optimization in Construction Supply Chain Management with Consideration for the SEAD Village

by Alec Zhou

Research Project

Submitted to the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, in partial satisfaction of the requirements for the degree of **Master of Science, Plan II**.

Approval for the Report and Comprehensive Examination:

Committee:

Professor Somayeh Sojoudi
Research Advisor

5/11/2022

(Date)

* * * * * * *

Professor Scott Moura
Second Reader

May 11 2022

(Date)

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Abstract

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by

Alec Zhou

Master of Science, Plan II in Electrical Engineering and Computer Sciences

University of California, Berkeley

Professor Somayeh Sojoudi, Research Advisor

Construction is a highly traditional industry that resists change, so its take-up of the past decades' advancements in supply chain management, optimization theory, and software system design has been accordingly slow. With disruption imminent, it becomes all the more necessary to carefully synthesize an approach to building modern construction technology that includes unhoused populations into the decision making process because of the tightly woven relationship between construction supply chains and informal housing settlements. With the ongoing student-led Sustainability, Education, and Arts Development (SEAD) Village project as a backdrop, we thus analyze the landscape of supply chain capitalism in construction and urge a conception of value that can consider the effects of supply chains on informal populations, going on to specify several components of an intelligent decision support system to achieve our aim. As the SEAD project continues over the next few years, this critique and system design forms the basis for further exploration of these issues.

To those who speak the language of the unheard

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Acknowledgments

This work would not be possible without my friends, family, and mentors. I would like to thank Professor Somayeh Sojoudi for sharpening my technical knowledge by teaching me optimization theory and graciously having me in her research group, my research group members for being math wizards, Professor Khalid Mosalam for being a steadfast advocate for our Solar Decathlon team, Professor Scott Moura for providing his class to develop our IoT system, and Professor Iris Tommelein for teaching me about the complexities of construction supply chains. I would also like to thank Professor Seth Wachtel, Sally Hindman, Reginald Gentry and the youth at YSA, especially Brandon Harris and Ana Caroline, for showing me the power of community and for keeping me focused on the fight against houselessness. I give my deepest appreciation to all of my friends and teammates in SHAC for their tireless work and inspirational enthusiasm for sustainable and equitable housing, especially Mia Campbell for co-managing our Solar Decathlon project and making SHAC possible. I give all my love to Sage Quinn for her unwavering love and support as the best partner I could imagine and for being the coolest person I know. Last but definitely not least, to my parents and sister, thank you for making me the person I am today.

Chapter 1

Introduction

1.1 Youth Houselessness in Alameda County

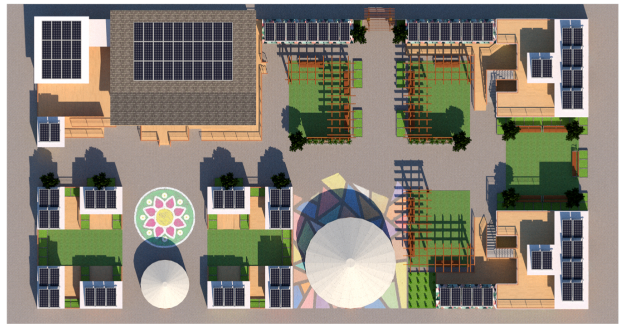
Unhoused youth often suffer long-lasting impacts on their capacities to be agents of change within their own lives and in their communities. On a worrisome upward trend, about 1,108 in Berkeley out of 8,022 total in Alameda County experienced houselessness in 2019, with youth (ages 18-24) comprising about 8% of that population. Homeless individuals in Alameda County are disproportionately of marginalized identities, where 57% identify as Black/African American and 14% as LGBTQ+ with even higher proportions in the youth population [1]. Coupled with a housing shortage that shows no signs of abating, in which there is a shortage of over 160,000 affordable homes in the Bay Area alone [2], there remains an urgent need to provide housing for our most vulnerable populations. At time of writing, there are over 12,000 vacant land parcels in Alameda County alone [3]. These vacant lots represent an opportunity for rapid construction of affordable homes and supportive housing.

1.2 Contextual Project Details

1.2.1 The SEAD Village and THEV

The Sustainability, Education, and Arts Development (SEAD) Village is an ongoing, student-led design and build of a village for unhoused youth in Oakland, CA, consisting of 24 residential units and an artist-maker community center. The project began in the late summer of 2021 with the design of the SEAD Center, the artist-maker community space that also acts as a competition entry into the Solar Decathlon Build Challenge 2023, which is an international collegiate green building competition hosted by the US Department of Energy. Construction of the SEAD Center will begin in August 2022 and complete in February 2023, followed sequentially by the construction of 8 individual tiny homes with about 80% reliance on volunteer labor, then a 2-story set of 8 modular residential units constructed primarily by professional labor, then another similar 2-story, 8-unit complex constructed with about

(a) Rendering of the SEAD Center, the artist-maker community space



(b) SEAD Village layout for 24 residential units

half reliance on volunteer labor. The landscaping and additional prefabricated community yurts will be done alongside the construction of the residential units. The SEAD Center is composed of modules that will serve as the technical basis for the development of the 2-story modular complexes. The entire site will be a cohesive village of 24 residential units, and the construction of the 3 different residential complexes will provide insight into an effective model to propagate across the Bay Area. Each quadrant is sized to the standard city lot size to fit on the many vacant lots available.

The owner and client for the project is Youth Spirit Artworks (YSA), a local interfaith nonprofit that provides job training to underprivileged youth in the Bay Area. As part of their "100 Tiny Homes for Homeless Youth" campaign, YSA built and now operates the world's first tiny house village for formerly unhoused youth aged 16-25, the Tiny House Empowerment Village (THEV), which is the origin and progenitor for the in-progress SEAD Village. The SEAD Village is thus the second village of YSA's campaign and plays a crucial role in taking the foundational lessons learned from the THEV and developing a scalable model for addressing youth homelessness in the Bay Area. The most useful foundational elements from the THEV project are: the scope of local community engagement and establishment of organizational credibility, the development of a construction workflow that effectively coordinates heavy involvement of community volunteers, and a precedent in navigating local permitting and other legal processes for the novel building types involved. The SEAD Village now aims to further refine these elements and adds a couple of new directions for exploration and concrete action, primarily focused on scalability and long-term effectiveness: the development of a robust construction supply chain consisting of strategic alliances with industry partners and the establishment of an academic program for exploring the complex network of societal and technical issues surrounding the project.

1.2.2 SEAD Village Research Areas

The SEAD Village acts as a launchpad for the further development of several research and educational areas embedded in the project's design process and future operations, currently including:

1. optimization in construction supply chain management,
2. Building Management Systems (BMSs) and algorithms for Internet of Things (IoT) devices,
3. devices and algorithms for networked microgrids,
4. makerspace-enabled education pedagogies for underprivileged youth,
5. panelized wall assemblies with a new-to-market stud system,
6. residential and commercial structural modules for emergency relocation,
7. the integration of several water conservation technologies into smart homes.
8. a novel daylighting sensor array

The first topic is the primary concern of this report with application to the SEAD project in mind, consisting of both the ethical and technical dimensions.

1.2.3 Sustainable Housing at California

As of Spring 2022, there are about 50 UC Berkeley students and about 9 University of San Francisco students working on the project, actively supported by faculty and staff at both universities with over 20 industry sponsors. Sustainable Housing at California (SHAC) is the student organization at UC Berkeley that initiated the project, currently with 30 students actively working on this particular project. SHAC also houses the Tiny House in My Backyard (THIMBY) project that has 15 active students working with the City of Richmond to pilot an ordinance that classifies tiny houses on wheels as accessory dwelling units, which has a complementary aim and similar project style in developing a scalable program for designing and building homes to address housing insecurity. In the coming years, these efforts will be further aligned through an official Berkeley curriculum; thus far, this is only partially realized in SHAC's student-run DeCal course Living Futures: Regenerative Environmental Design and a substantial IoT component of the SEAD project that additionally involves over 20 students from the Berkeley course Civil Engineering 186/92A Design of Internet of Things for Smart Cities to build out a custom Village Management System for coordinating all IoT devices involved.

1.3 Contributions

I am a co-founder of SHAC and serve as a project manager for the SEAD project; some of my contributions and ongoing roles for this current project include defining the overall project vision and operations, supervising the design process for the SEAD Center's MEP systems, initiating and maintaining nearly all sponsor and partner relationships, designing and overseeing the IoT project in CE 186/92A, and managing coordinating media and publicity. It has been an incredibly rewarding experience to lead and grow with my fellow students in this momentous effort; I could not have synthesized the multidisciplinary content of this report without the wide range of people and ideas I have encountered throughout my involvement with SHAC. Much like the village itself, this report is and will remain an ongoing project that requires further elaboration over the next few years, but I have made every effort to present the work done thus far as cohesive.

1.4 Report Overview

The combined goal of Chapters 2 and 3 is to lay out the conceptual groundwork for the SEAD village as a platform for further research in optimization for construction supply chain management. This work cannot be done without heavy consideration of the social implications for the residents of the community, who constitute a highly marginalized population. To achieve this, we operate at an intersection between optimization, construction supply chain management, and critical theory. It is immediately important to note the style and content of this report, the audience for which may seem at first extremely limited due to the historically sparse overlaps between the aforementioned fields, not to mention the rifts in general between engineering and the humanities, techne and poeisis [4], cybernetics and bodies [5], technical artifacts and politics [6]. To ignore the lives of the actual residents of the SEAD Village by creating a purely technical report is tantamount to positioning ourselves as scientists experimenting on lab mice; the utmost care must be taken not to detach from the social reality of human livelihoods, to be enamored by abstractions, lest we become the "poor technicians of desire – psychoanalysts and semiologists of every sign and symptom" [7], engineers and designers of every form and formula – who would subjugate underprivileged livelihoods to the cold bureaucracy of neoliberal institutions.

Chapter 2

Critique of Construction Supply Chain Management and Optimization

2.1 Introduction

The historical development of supply chains traces a self-optimizing acceleration of commodity production and circulation, a progression visible through many possible sets of chronological historical markers. One such popular genealogical account proceeds from Industry 1.0 through 4.0, from the first factories to the now global network of near instantaneous commodity exchange through e-commerce. From the capitalist perspective predicated on the language of the neoliberal *business ontology*, industry innovation is the driver of this logistical acceleration, an acceleration of the production of "value" through design iterations on goods, services, business models, and supply chain configurations. Mark Fisher uncovers this business ontology as the foundation of *capitalist realism* [8], marked by the inability to conceive of a notion of value beyond market value or without business terminology (and more generally, the possibility of any alternative system beyond capitalism) in addition to the insistence that this market value is solely a product of technical and apolitical factors such as supply, demand, and technological innovation. However, emerging critical perspectives in logistics and supply chain management have "challenged the prevailing view of logistics as a purely technical or apolitical science, pointing to the field's origins in war and the ongoing acts of violence exacted in its name" [9]. In particular, the inseparability of construction supply chains, the housing market, and human livelihoods motivates this brief study of and solution sketch to one specific dimension of this ongoing violence: the dispossession of housing from marginalized peoples, i.e. the creation and maintenance of the so-called informal housing "industry," through the logic of business ontology and supply chain capitalism.

The effects of construction supply chains on houseless populations are inherently externalities, largely unseen in the flow of capital that frequents corporate boardrooms and academic ivory towers. It is therefore insufficient to merely identify these effects and decry capitalism; per Slavoj Žižek as analyzed by Mark Fisher, anti-capitalist sentiment has already been appropriated for the further reinforcement of capitalism and can be seen everywhere in popular media, corporate marketing, and academic studies [8]. Instead, we must grasp the actual mechanism of capital and engineer tools that can conceive of a notion of value that lies beyond business ontology and is thus able to see the typically unseen.

We know that this is possible. Just a few decades ago, concerns for sustainability were almost entirely unseen in the supply chain management literature, but a quickly growing set of supply chain researchers are now explicitly incorporating sustainability metrics into their work [10]; climate change is an externality no more. To move towards something similar for the social impacts of supply chains, this chapter proceeds as follows: we first introduce Anna Tsing's concept of supply chain capitalism to gain perspective on the key players and operations of the construction supply chain, then go on to unearth the accelerative mechanism of capital a la Gilles Deleuze, Felix Guattari, and Nick Land as it relates to optimization, and finally make use of Michel Foucault's concept of biopolitics to simultaneously examine the effects of technologies for supply chain management and construction on populations and motivate the design of a software system for construction supply chain management. This software system is sketched in Chapter 3.

2.2 (Construction) Supply Chain Capitalism

Anna Tsing theorizes supply chain capitalism as a model through which to analyze the complex landscape of "commodity chains based on subcontracting, outsourcing, and allied arrangements in which the autonomy of component enterprises is legally established even as the enterprises are disciplined within the chain as a whole" in order to understand the violence enabled by current supply chain theories and practices [11]. In the construction domain, the global set of supply chains is a highly heterogeneous complex composed of engineering and design firms, construction contractors, subcontractors of various trades, project owners and clients, governmental entities, and research institutions, all with competing interests and resources [12]. To handle the complexity of this landscape of various organizations, the predominant approach to construction supply chain management is from the local perspective of one or a few entities looking across their particular industry verticals and horizontals. As examples, the Integrated Project Delivery method for the design and build process provides a framework for establishing relationships and facilitating information sharing between owners, architects, engineers, and contractors [13], and the Vendor Managed Inventory method allows suppliers to take control of their local supply chain [14]. Analyzing capitalism through supply chains thus allows us to simultaneously draw conclusions at local and global scales.

Supply chain theorists also near-religiously revere frameworks such as Lean and Target Value Delivery as holy grails of increased process efficiency, worker productivity, customer satisfaction, and stakeholder coordination, touting the value provided to stakeholders that include investors, project owners, and companies at every stage of the supply chain. The drive for continuous improvement is thus justified by this perceived value, and this philosophy of perpetual innovation thus constitutes the natural movement of capital that seeks to selfoptimize at every moment for those who can afford it. Even with research works that recognize and attempt to address the lack of social concern in the literature of supply chain management [10], they speak of "corporate social responsibility" and are unable to think outside of the language of business ontology.

Despite the value provided to those actively participating in the supply chain, the typical stakeholders considered do not include the marginalized communities whose lives are affected by these construction projects due to their lack of funds and visibility. It is this lack of visibility and profitability that excludes our most vulnerable populations from consideration when conducting construction projects. The neoliberal conception of value does not extend to them; through this exclusion, unhoused individuals are forced to create informal settlements that remain vilified by property owners. Additionally, because housing projects for low to no income populations are few and far in between, there are little to no construction supply chains centered around serving them in the United States. This fact is painfully clear in nonprofit Keystone Mission's attempt to build a shelter that still has not yet found a door after 8 months in construction, over double the duration of the initially planned construction schedule [15]. In general, the organizations dedicated to addressing the housing crisis are made to rely on the altruism and charity of capitalists, further confirmed from my close involvement with Youth Spirit Artworks.

2.3 Capital and Optimization

We must then conceive of a concept of value that moves beyond the naive neoliberal confinement of value to market value and can consequently prioritize ethical dimensions in its calculation that enables supply chains to empower marginalized communities in a way that is not necessarily profitable at the outset. To do this, it is useful to elaborate upon the actual accelerative mechanism of capital that lies contrary to the answer provided by business ontology. Gilles Deleuze and Felix Guattari argue that capital proceeds by *territorialization* and *deterritorialization* [16]. At one end of the spectrum, capital acts as a recording surface on which to conduct the quantification and reification of materials and labor through legal processes, accounting, and datafication in order to render them graspable; it produces a territory and code. At the opposite, capital levels a universal playing field to allow for the equivalent exchange of different entities; it performs a liquidation and de-signification.

It is in this way that financial capital, social capital, human capital, technological capital, and semiotic capital blend into each other and thus allow the capitalist to speak of "value" in a universal sense. This, in turn, enables the use of language and representation to appropriate and manipulate various types of capital for production, reproduction, circulation, consumption, and accumulation. In this way, capital constitutes a self-optimizing process with humans in the loop for which acceleration is an innate property that effects digitization, decentralization, and diversification. These effects emerge as industry trends in supply chain management and are recognized through the increasing reliance on outsourcing and interfaces for electronic exchange, emphasis on inter-organizational relationships, and rise of multi-national companies and global operations, this globalization of supply chains creating channels through which capital accelerates and pockets in which capital overaccumulates. As advances in technologies for construction supply chain management continue to be conducted in the language of business ontology, informal communities are further deprived of their agency in determining the flow of capital. As evidence of these natural inclinations of capital, a study of 250 researchers found that the aspects of supply chain management concerning people and ethics were the least addressed research trends that research directions involving big data and analytics are the most “hyped” areas [17].

The purely technical approach is not exclusive to optimization research but pervades much of the sciences and mathematics, though optimization in particular is well suited as a case study to exemplify the unconditional acceleration of capital. Nick Land laid the groundwork for an *accelerationist* philosophy, in which he appropriates Deleuze and Guattari’s characterization of capital and urges a maddening intensification of its acceleration [18]. Though "optimization" is a central theme of accelerationist works, it is primarily treated in a general, almost colloquial sense. Here we present accelerationism as the predominant ideology of academic research in mathematical optimization to make this relationship more precise. Trivially, the problems studied in mathematical optimization must be formulated as problems with identifiable variables and fully defined relationships; thus, the formulation of these problems are subject to the available datasets and the various sources of academic, government, and industry funding that determine what data are collected and what problems are studied. The observation that supply chain management is not apolitical nor purely technical applies the same to optimization research. The neoliberal conditions under which research projects are funded are amenable to a wide variety of ethically questionable research in optimizing police deployment [19] and facility location [20] [21] and military operations in wartime troop logistics [22] and weapon portfolio management [23]; the military-industrial complex is stronger than ever.

That is not to say that there is not a wide variety of commendable research directions, for example addressing the robustness of energy infrastructure or sustainability of logistical networks. But even in these commendable areas, the application of research into industry is distributed unevenly in the neoliberal milieu and first benefits affluent geographical locations before waiting for the benefits to "trickle down" to marginalized communities. It is not that optimization research is entirely blind to ethical and societal risk factors; in fact, some works explicitly include these factors in their objectives [24], but the nature of multi-objective optimization problems allows for certain objectives to be weighted above others, and the imperative profit motive of business ontology designates those ethical and societal dimensions as second class objectives.

2.4 Biopolitics and Construction Supply Chains

The uneven flow of capital as enabled by its accelerative properties engenders the "super-exploitation" of populations, defined through noneconomic factors such as "gender, race, ethnicity, nationality, religion, sexuality, age, and citizenship status" in a way that allows "exploitation greater than might be expected from general economic principles" [11]. This is evident in the fact that sexual and racial minorities make up a disproprortionately high proportion of the houseless population [1]. To better contextualize the effects of the construction supply chain on marginalized populations, we must utilize a heavily documented concept in the sociological critique of power: Michel Foucault's *biopower*, whose language and practice is conducted through *biopolitics*. Biopolitics refers to the politically sanctioned relationships between organizational entities and populations that organize the lives of human populations. At its conception, the concept referred to the physical regulation of bodies in physically localized institutions such as prisons, schools, factories, and military barracks, but has since received several further elaborations and extensions. Several authors have noted that biopower and biopolitics extend beyond physical limitations, for example into the cognitive and technological realm as psychopolitics [25] and the sexual and semiotic realms as pharmacopornographic power [26]. This evolution aligns with arguments concerning the decentralization, diversification, and digitization effects of an accelerating capital that "invades the body; routinizing, reprogramming, plasticizing it" [18].

Nick Land uses the concept of biopower as a deconstructive tool to conjure up a frightening image of the body under capitalism as "a partial- or open-system, transducing flows of matter, energy, and information" that is "able to function as a module of economically evaluable labor power." This "industrial-informational body is . . . defined by its place among the machines, and redefined ever more exactly by its migration across the mutant sutures in machinic continuum: where the machinery was incomplete is you" [18]. Indeed, this depiction of the body subjugated by biopower invokes grotesque images of malleable limbs and programmable minds, subject to the biopolitics of corporations and surveillance states. The use of occupancy sensors in factories provides exactly the bodily information needed for productivity maximization, for biopolitical control. The use of discrete event simulation for process improvement for optimizing the actions of workers exerts exactly this same biopower. The use of RFID tags for tracking the transportation of materials at the same time as employees are tracked in the same computer systems blend together organic and inorganic entities, where truck drivers and their shipments are considered in the same stroke, fellow variables in a route planning optimization problem. These biopolitical technologies enable a conflation of self-exploitation and super-exploitation as workers are incentivized to align their thoughts and movements with the further acceleration of capital all the while their various identities are subsumed into capital's calculative mechanism.

As biopower exerts control over the populations it can conceptualize, so does it damage those excluded from its direct scrutiny by sustaining the conditions that produce informal housing from their exclusion from the economy and the flow of capital. While the business ontological notion of "value" remains in effect, the houseless who do not adhere to the capitalists' ideas of proper living and continual entrepreneurship are made to either relocate further into the margins or be subject to a disciplinary institution that seeks to "fix" them. The long-standing struggle in Berkeley over People's Park offers a perfect example for this situation. In the latest attempt to construct a building for both student and supportive housing, UC Berkeley has an agreement with a local nonprofit to relocate those currently in informal settlements on People's Park to a nearby inn that would be repurposed as transitional housing. First, this means that those at People's Park are all but ineligible for permanent supportive housing in the building that will be constructed on their homes, instead given to those already accounted for in government programs who are able to meet the standards for their application process. The University explicitly states that "the demographics of the residents in the proposed supportive housing will therefore be linked to the funding source" from a set of government programs [27]. Second, the need to repurpose the local inn for transitional housing further indicates that houselessness is addressed as an afterthought in construction supply chain management, with construction supply chains with the goal of housing the unhoused only appearing briefly on an ad-hoc basis. The growth of informal housing settlements is thus sustained in the cycle of top-down intervention and discontent with neoliberal policies.

2.5 Towards an Intelligent Decision Support System for Construction Supply Chain Management

This sullied picture of biopower lacks consideration for its constructive aspects; to remedy this negative depiction of the subjugated body, we must turn to Donna Haraway's figure of the cyborg. A cyborg is a "cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction," a "fluid, dispersed, networking techno-organic-textual-mythic system" [5]. Architects have their CAD tools, CNC mills and building models, building codes and narratives of proper architectural design; engineers, their formulas and block diagrams, circuits and robots, system design principles; supply chain practitioners, their discrete event simulators, factories and logistical networks, lean thinking. "Hence we are all handymen: each with [their] little machines" [16], constructing a social reality with our technologies at the same time as these technologies permeate and mediate our interpersonal and interorganizational interactions. The false objectivity of an apolitical science is thus a concession to the flow of capital under business ontology, an self-induced myopic delusion that preserves the informality of unseen populations.

Even as the development of optimization theory for construction supply chains begins to recognize the importance of fair labor conditions and other social metrics [10], it has not yet begun to recognize its conformity to the capitalist conditions that displace and alienate the informal populations that live in the margins. Further, even if it begins to identify and formalize the metrics for the inclusion of the unhoused, the unhoused themselves are not necessarily part of the decision making process. Thus, the design and implementation of a technological system that optimizes for social metrics like fair trade and societal investment [28] is not enough by itself. Instead, what is needed is the extension of our cyborg realities beyond the confines of the various trades and professions that already operate in the purview of capital, that are visible in the supply chain, that can be spoken about through business ontology.

The technology of expert systems that support decision making in business contexts exhibits exactly this limitation of the regulation of capital to the "experts" of certified trades and professions. Requiring data to come from domain experts does indeed make sense for producing value under neoliberalism, but this practice explicitly excludes informal populations from consideration at the outset. The next chapter lays some groundwork for the inclusion of some ethical dimensions in the decision making process from the perspective of a general contractor, but more work needs to be done in formalizing the inclusion of the unhoused population that has most to lose from an exclusionary construction supply chain.

Chapter 3

Towards an Intelligent Decision Support Platform for Construction Supply Chain Management

3.1 Expert Systems for Construction Supply Chain Management

3.1.1 Insufficiency of Expert Systems

Expert systems are software applications that support decision making in a particular domain using information obtained from domain experts. Since their original conception in the 1980s, expert systems typically employ rule-based "if-then-else" statements or, in some cases, fuzzy logic [29]. However, with the explosion of computational power and machine learning capabilities in the past decade, relying on developing these simple rules is tedious and inefficient. Additionally, the task of knowledge acquisition to fill the system is the most time consuming and difficult task in creating an expert system [30]. With the introduction of Building Information Modeling and growth of other data available about construction projects, there is an opportunity for augmenting the outdated notion of an expert system with this growing data in the construction domain to complement the manual information provided by domain experts.

3.1.2 Updating Expert Systems with Model-Driven Architecture

Typical components for expert systems are storage for a knowledge base, a knowledge acquisition pipeline, an inference engine using rules and mathematical models, a rule and model development environment, and a user interface to manage all the aforementioned components. This high level component description and the vast landscape of tools for each component motivates a Model-Driven Architecture framework, a scalable software design approach that is modular and tool-independent [31]. There has been no attempt at synthesizing this model-driven conception of an expert system with consideration of the vast landscape of tools now available for the various components of these improved expert systems, for which we provide an initial sketch for construction supply chain management. To differentiate our approach from the typical expert system, we refer to our updated conception as an intelligent decision support platform.

A typical expert system development workflow proceeds through identification, conceptualization, formalization, implementation, and testing [32], which we adopt for our approach. This section of the report involves the first stage for construction supply chain management from the perspective of a general contractor, particularly emphasizing the optimization techniques for implementation in the inference engine. To achieve this, we specify the components and models needed for this intelligent decision support platform and use several existing literature reviews to provide a perspective on the landscape of optimization areas for the construction supply chain.

3.2 Idiosyncracies of Construction

3.2.1 Construction as Compared to Manufacturing

Supply chain management frameworks such as Lean and Six Sigma have seen great successes in the manufacturing industry and have spurred the development of expert systems for manufacturing [33], but there have been difficulties in applying the same principles and techniques to the construction industry due to a number of important differences. In comparison to manufacturing, the construction industry is highly fragmented with adversarial practices between participating parties, lacks information sharing across firms, is marked by one-off projects, suffers from high variability in material and labor flows, and relies on reactive capacity planning [34]. Thus, approaching supply chain management in construction requires a mixture of qualitative and quantitative approaches that heavily consider the idiosyncrasies of the construction domain. For example, the selection of suppliers to minimize costs and emissions can be formulated as a formal optimization problem, but the development and maintenance of these relationships requires non-formal approaches with humans in the loop under ever-changing conditions. Many issues in construction can be and are being substantially addressed by further adoption of Building Information Modeling [35] and other developing digital technologies with an associated increase in collaborative information sharing, all of which are aligning to allow the development of mathematical models to analyze the large influx of new data. Adoption of these technologies and techniques is still in its nascent stages for the construction industry, making it all the more urgent to synthesize a framework to support intelligent decision making systems for construction.

3.2.2 Role of the General Contractor in Construction Supply Chains

There are roughly three phases in construction projects, proceeding from planning and design to procurement to construction and delivery, in which the main entities are the general contractor, subcontractors, suppliers, designers, and the project owner/client. The general contractor plays a substantial role in each of these phases, interacting with virtually all entities. In particular, they receive the design from the designers and provide feedback, receive project control instructions from the owner and provide construction plans, select products from the subcontractors and suppliers and receive these products, then finally construct the project. Due to their extensive interactions with nearly all key entities, general contractors are very well suited to take a supply chain management perspective in conducting their activities.

3.2.3 Optimization Areas for Construction Supply Chain Management

We identify three main areas for the application of optimization in construction supply chain management, which are project time-cost-quality management, supplier selection, and supply chain network design. In our three optimization areas for construction supply chain management, we outline infrastructure tools to be used, objectives to be formulated, the data to be collected and algorithms to be implemented. Typically, "construction supply chain management" refers only to the resource and stakeholder management aspect of construction with emphasis on the relationships between organizations, but we use the term more broadly to encompass construction project activities, which are the endpoints of construction supply chains. This represents a end-to-end perspective on the overall supply chain, best suited for the general contractor that engages with both suppliers and project owners.

3.3 Tools for Building an Intelligent Decision Support System

3.3.1 Knowledge Acquisition Pipeline

Some tools that perform the role of the knowledge acquisition pipeline by providing a platform for data ingestion are AWS Cloud-Formation, Amazon Firehose, Amazon SQS, Amazon Kinesis, AWS IoT, AWS Lake Formation, HDInsight, Confluent, IBM MQ, Apache Kafka, Talend Data Fabric, Azure Data Factory.

3.3.2 Storage for Knowledge Base

Some tools that provide data storage for a knowledge base include Apache Hive, Apache Drill, Cloud Spanner, Amazon Aurora, Hortonworks Data Platform, Apache Hadoop Distributed File System, Amazon DynamoDB, Datastax, MongoDB, Cloud Spanner, SQL Data Warehouse, Azure Data Lake, Azure Blob, Amazon S3, Snowflake, Google BigQuery, Amazon Redshift, Amazon RDS, and Databricks Delta Lake.

3.3.3 Model Development Environment

Some tools that enable model development workflows include cvx, CPLEX, GAMS, TensorFlow, PyTorch, scikit-learn, RapidMiner, AzureML, and KNIME Analytics Platform.

3.3.4 User Interface

Some tools that allow easy visualization dashboards include Alteryx Designer, Tableau, Domo, Microstrategy, and Qlik.

3.4 Time, Cost, and Quality Management for Project Planning

Construction projects notoriously run late due to scheduling problems, go over budget from bad cost management, and invite litigation due to insufficient quality control. There is an extensive and still growing literature on each of project scheduling, budget management, and quality control, but they are typically addressed alone or pairwise [12]. Formulating a time-cost-quality trade-off problem (TCQTP) allows for an integrated approach to all three interrelated problems. Quality can generally be formulated in a number of ways in either the objective or constraints, including the amount of rework required, project risk, a function of cost and duration, an assumed parameter in different execution modes [36], or even environmental impact and worker safety [12]. Typical formulations of the problem can include information about construction methods, material qualities, scheduling activity durations and dependencies, construction crew sizes and configurations, overtime policies, project crashing, rework time and cost. The TCQTP can be typologized based on the whether the problem has discrete or continuous decision variables, has single or multiple resources, solves for a single objective or multiple objectives, or uses exact or heuristic algorithms [36].

3.4.1 Decision Variables and Parameters

In the literature, researchers have used continuous decision variables for the proportion of rework time to cost [37], activities cost [38], activities start time [39] [40], activities finish time

[41] [40] [38], and activities duration [39] [42] [43]. We can also use discrete decision variables for completion date [37], activities duration and non conformance risk activity selection [44], activities execution mode/start time and repair work/start time [45], activities finish time and execution mode [46] [47], crashing and activities execution mode [48], reduced time relative to a baseline [40], activities subcontracting options [49], activities execution mode [50] [51] .

3.4.2 Objectives

All works address some combination of cost, time, quality, but with different formulations. Some single objectives for the TCQTP are to minimize the total project time alone [52], maximize project quality alone [38], minimize project cost alone [45], minimize total project time, minimize project cost, and maximize project quality in three interrelated single-objective problems [52] [39] [46] [47], solve for a single objective to minimize cost, risk, and decrease in quality [40], minimize a single weighted sum of cost, duration, and quality [42], minimize a single weighted sum of the proportion of rework time and cost [37], and minimize crash times and non conformance risk activities [44]. Using a multi-objective to minimize total total project time, minimize project cost, and maximize project quality is also a popular approach [43] [48] [53] [49] [50] [51].

3.4.3 Optimization Problem Types and Algorithms

To solve the TCQTP, we can formulate a mixed-integer linear program to solve with an exact algorithm [37] [44] [40], formulate a binary integer linear program to solve with an exact algorithm [52], solve linear and nonlinear programs using an exact algorithm with epsilon-constraints [41] [39], solve a continuous nonlinear program with an exact algorithm [38], or solve a integer linear and nonlinear program using an exact algorithm with epsilon-constraints [46]. We can also formulate a continuous nonlinear program to solve using a metaheuristic approach of the Immune Genetic Particle Swarm Optimization [42], a continuous nonlinear program using a metaheuristic approach of the Hybrid Multiple Objective Artificial Bee Colony with Differential Evolution [43], a binary nonlinear program using a metaheuristic approach of the Shuffled Frog-Leaping Algorithm [45], a binary nonlinear program with a metaheuristic approach of the Electromagnetic Scatter Search algorithm with epsilon constraints [47], a binary linear program using a metaheuristic approach of the Multi-Objective Imperialist Competitive Algorithm [48], a binary linear program using a metaheuristic approach of the Multi-Objective Genetic Algorithm [53], a binary linear program using a metaheuristic approach using the Fuzzy Clustering-Based Genetic Algorithm [49], a binary nonlinear program using a metaheuristic approach of the Multi-Objective Ant Colony Optimization algorithm [50], and a fuzzy nonlinear program to solve using a fuzzy-based adaptive-hybrid genetic algorithm [54].

3.5 Supplier Selection

The supplier selection (SS) problem addresses both procurement and stakeholder management and has been widely studied [55] with at least 20 existing literature reviews in the past 30 years because of the wide applicability to a large number of industries.

3.5.1 Decision Variables and Parameters

Possible decision variables include whether a supplier is selected, units of product to purchase from a supplier [56] [57] [58] [59] [60] [61] [62], facility selection, production capacity, equipment capacity, transportation type [61], partial order amount [58], amount to pay suppliers [60], amount of material transported between parties, and amount of overtime production [62]. Possible parameters are discount brackets and rates [56] [60], unit ordering costs [57], cost of setting up an order [63], inventory holding costs [57] [59] [61] [62] [58], unit inventory depreciation costs [61], unit purchase costs from a supplier [57], supplier production capacity [63] [64] [62] [58], customer demand [57] [64] [62], stochastic demand [58], quality level [59] [60], price elasticity [63], defect rates [64], delivery reliability [60], idle labor cost, idle equipment cost, severance cost, recruitment cost, costs, available labor time, shelf life duration, lead times, product availability [61], transportation, unit [61] [58], backorder cost, inventory holding emissions, procurement emissions, order placement emissions, transportation emissions [58], supplier reputation, and after sales service [64].

3.5.2 Objectives

The supplier selection problem can seek to minimize total expected cost over a horizon [57], minimize total cost at one instance of time [56], maximize total profit rate [59], simultaneously maximize total purchase value and minimize total purchase cost [64], simultaneously minimize purchase cost, maximize quality, and maximize reliability [60], simultaneously minimize total investment and operational costs over a time horizon [61], simultaneously maximize expected profit and conditional value-at-risk [62], simultaneously minimize cost and emissions [58], or simultaneously minimize cost and maximizing service level [65].

3.5.3 Optimization Problem Types and Algorithms

Some problem formulations and their algorithms include a integer linear program using an off-the-shelf solver [57], a two-stage stochastic mixed-integer nonlinear program using a branch-and-cut algorithm [56], a two-stage mixed integer nonlinear program using three custom algorithms that involve the off-the-shelf solver LINGO [63], a goal program to solve using an off-the-shelf solver LINGO [64], fuzzy multi-objective mixed-integer program to solve using an off-the-shelf solver [60], a mixed integer linear program to solve using an off-the-shelf solver [61], a two-stage stochastic mixed integer linear program using the multi-cut Benders decomposition method [62], a multi-objective mixed integer nonlinear program using a multi-start local search heuristic algorithm, and adaptive epsilon-constraint algorithm, an interior point method, and an evolutionary search algorithm [58], and a stochastic multi-objective mixed integer program using an off-the-shelf XPRESS solver [65].

3.6 Supply Chain Network Design

In order to facilitate the complex resource and information flow in a supply chain, supply chain managers must take a systems perspective on the many resources, suppliers, facilities, and customers involved in the supply chain network. Thus, typical supply chain network design problems concern a directed acyclic graph with suppliers, facilities, and customers as nodes and optimize the flow of resources between each. Recent trends are beginning to address the importance of sustainability and social concerns in designing these supply chain networks, but more work is needed in these areas [10].

3.6.1 Decision Variables and Parameters

Decision variables can include the amount of product shipped between suppliers, amount of product shipped from suppliers to customers, amount of product product made by supplier, the connections between suppliers, the connections between customers, and whether environmental protection is selected. Several possible parameters for the problem include fixed cost of setting up an alliance, fixed environmental protection investment, environmental protection level, unit transportation cost, unit supplier processing cost, production capacity, forecasted customer demand, and unit sales revenue for a product [66].

3.6.2 Objectives

Possible variables to include in the objective also include "greenness," costs of linkage/establishment of alliances, holding/storage costs, transportation costs, fabrication costs, backorders, and shortage cost/penalty [66].

3.6.3 Algorithms

Several of the techniques to the supply chain network design problem include goal programming approach to formulate a mixed-integer linear program to solve using ILOG CPLEX [67], a mixed-integer nonlinear program to solve using a branch and reduce algorithm [68], a mixed-integer nonlinear program to solve using the logarithmic-quadratic proximal prediction-correction method [69], a mixed-integer nonlinear program to solve using a backward induction technique [70], a stochastic mixed-integer nonlinear program to solve using an AMPL solver with GAMS [71], a mixed-integer nonlinear program to solve using a memetic algorithm employing the Taguchi method [72], and the transformation of a multi-objective to a single-objective mixed-integer linear program problem to solve using CPLEX [66].

Chapter 4

Conclusions and Future Work

The Sustainability, Education, and Arts Development Village is an ongoing design and build project involving students, faculty, nonprofits, private companies, and unhoused youth to address houselessness in the Bay Area with several research directions. In particular, this report sets up a theoretical basis for further exploration in developing technologies for construction supply chain management. In light of the ties we have drawn between optimization theory in construction supply chain management and the maintenance of the informal housing industry, we argue for a systematic approach using both quantitative and qualitative methods that emphasizes the inclusion of informal populations into decision making processes. To this end, we have motivated the need for an updated conception of expert systems using Model Driven Architecture and laid the groundwork for further specification of the system design, particularly for the inference engine component in application to construction supply chain management, and provided a theoretical landscape of construction supply chain capitalism to sketch a holistic approach to approaching houselessness with the power of optimization theory and software design.

As the SEAD project continues over the next several years, the importance of ethics in optimization and construction supply chain management must be further elaborated alongside a practical approach to building technologies that work for the most marginalized communities. In particular, the Model Driven Architecture component of the sketched intelligent decision support system needs to be formalized using the standards set out by the Object Management Group, including further specification in the Unified Modeling Language, the Meta-Object Facility, XML Metadata Interchange, Enterprise Distributed Object Computing, the Software Process Engineering Metamodel, and the Common Warehouse Metamodel, in addition to the data transformations between a computation-independent model, platform-independent model, and platform-specific model. There also must be more work done in incorporating real-time feedback from non-experts into the decision making process, for which we can take inspiration from the Chilean Cyberfolk project. Further specification of ethical metrics is additionally required.

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