Using Time and Material (T&M) to Develop and Guide Holons in a Design and Construction Project - The results of Two Case Studies.

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Abstract

Humans evolved as socially collaborative builders, cooperatively reshaping nature for shelter, creating villages and towns through collective social engagement. This behavior, identified as niche-construction [1], enable humans to cooperatively shape the earth into an ecosystem of millions of inter-linked built environments. As a result, the design and construction industry generate 3% of global GDP [2]; however, it is a sector in which its productivity improvement output lags when measured against other sectors. Production in the manufacturing, retail, and agriculture sectors has grown by 500% since 1945, while output in the construction industry has increased by less than 2% [3]. It is an industry plagued with system failures, including schedule delays, budget and cost overruns, and contractual disputes. Almost 80% of large projects experience cost overruns of more than 30% and schedule delays of 40% [4]. If the human need to build is genetically embedded within humans as builders, why is the design and construction industry so troubled? We argue that the industry's failures are a result of misapplied project controls, proposing that traditional controls fail to support the front-line builders, who, in addition to actively building the project, are also fulfilling their evolutionary needs as human niche-constructors. We argue that this behavior is driven by communal and adaptive social task-level planning, represented through emergent agent collaboration which is hindered by traditional project controls. As a result, the adaptive agent-systems conflict with the established systems, reinforcing the inefficiency and failures that plague the industry. In the following two case studies, we examine and measure the effects of controls for project change management and how they impact the overall controls systems for projects and the entire design and construction industry. We propose changes for these systems that will improve efficiency and productivity on projects and in the industry and recognize and leverage the role of design and construction teams as niche-constructors, fulfilling their evolutionary need to build.

Introduction.

Humans create-built environments. Like most living things, humans are niche-constructors [5], shaping the planet to meet their needs. However, unlike other animals, humans combine and specialize their abilities, leveraging individual and group expertise and experience. As niche-constructors, humans collaboratively created agriculture, domesticated animals, constructed cities, and developed social market economies to establish and support built-environments, reshaping the earth's ecosystems to meet their needs.

In the process, humans create and inhabit complex systems. The modern design and construction industry is a human-created complex system. It is top-down and market-driven, supporting the capital-intensive and risk needs of thousands of project-based organizations [6], which plan, design, and build construction projects. It is a global industry that includes the design professions of architecture and engineering, general and specialty building trades, and supply chains of material vendors and specialty suppliers.

In this paper, through a review of two case studies, we explore how construction projects deal with complexity through the lens of change management processes. We examine the effects of this management and its impact on project schedule and cost and its ability to recognize and deploy the human evolutionary need to build.

Case Study One - reviews of the project’s existing, top-down, centralized system for project change orders (CO), and -

Case Study Two -reviews the results of an innovative bottom-up decentralized, system which was implemented to correct the failures identified in Case Study One.

This paper is organized as follows-

- Introduction
- Case Study One – review of the existing system of project change controls.
- Literature Review – where we review the existing systems of construction change management controls, holons and holonic teams, and human niche-construction
- Research Question – Outline of the question identified from Case Study One, and proposed solution
- Methodology – How we proposed to implement the solution
- Case Study Two – Implementation of the Methodology
- Analysis – Results of the Implementation
- Contribution – How this work can add to the body of knowledge for managing project change
- Conclusion and next steps.

In this Introduction, we review the fundamental concepts of traditional change management controls for design and construction projects.

Then, we present the results from Case Study One – a results of a review of the existing CO processes for a large, long duration hospital project in California.

Then, in the Literature Review, we present -

1. A review of traditional change management project controls for construction projects,
2. How construction projects evolve into Complex Adaptive Systems (CAS)
3. The emergence of Holons in CAS
4. And the driving force of Human Niche-Construction in creating built environments

Then, as a result of that review, we outline the Research Question – "Do traditional construction project controls thwart the human need to build, creating an industry that is inefficient and unproductive?"

Then, we identify the Methodology we used to test the Research Question.

Then, in Part Two, we outline the deployment of that Methodology, delineating, with metrics, the results from Case Study Two.

Then we Analyze the results from the deployment of the Methodology.

Then, we outline the Contribution of this Case Study to the body of knowledge on managing design and construction projects.

Then, in the conclusion, we outline the next steps for our research.

Introduction – Fundamental Concepts of Design and Construction Project Change**.**

Change Orders (COs) [7] exist to manage the dynamic nature of design and construction projects. For example, change may be a result of incomplete design information, deferred work, owner changes, unforeseen site conditions, or other issues.

Design and construction contracts are developed not only to plan and build a project but to manage project risk. Contracts are written to mitigate and assign scope, cost, and schedule risk, with "changes in the work" clauses that define the processes for documenting and submitting COs [8].

Most contracts follow the Design-Bid-Build (DBB) [9] methodology, where the project owner, referenced in this paper as the Owner, holds separate contracts with the design and building teams. The design team, referenced in this paper as the Architect of Record (AOR), has contract liability for producing design documents for a building permit, issued by the Authority Having Jurisdiction (AHJ). The Owner then enters a separate contract with the builder, or General Contractor, referenced in this paper as GC, to build the project according to their experience and understanding of the AOR's design documents. The GC typically subcontracts to multiple specialty trade builders, identified as Trades, who assist the GC in building the project.

This contracting process dictates the legal communication between the Owner, AOR, and GC/Trade teams during design and construction. Change is typically initiated through Requests for Information (RFI) [10]. Each party controls its RFI process. Construction RFIs (CRFI) are written by the GC/Trades and submitted to the Owner. AOR RFIs (ARFI) are written by the AOR and submitted to the Owner. The Owner may also write ORFIs to initiate change to the work.

CO management.

For a GC/Trades change, the Owner will issue a CO to the GC for review and pricing, who returns with an estimated cost and schedule impact for the Owner's review. Once approved, the CO will be incorporated into the permitted project documents, and the GC will begin the work.

CO review and negotiation steps may develop between the Owner and GC/Trades, before CO approval. As a result, Reimbursable time and materials (T&M) [11] may also be used to remedy COs under review. T&M enables the GC/Trades to begin the disputed work and submit labor timesheets and material invoices tracking the work as it is completed. However, T&M is typically not used for an entire project or even large areas where there is a mix of multiple trades and potential overlap between existing bid contract work and the CO work.

Results of Case Study One

Case Study One lists the results of four years of CO workflows on a large, multi-year California hospital project using traditional CO processes. The project's construction contract was a Guaranteed Maximum Price (GMP) [12] valued at $1.2b. A GMP contract is a variation of the traditional DBB contract. Like a DBB, the GC self-performs a percentage of work while managing multiple specialty Trades such as electrical, plumbing, drywall, etc., who do most of the project scope. Before the project begins construction, the GC and Owner agree to a GMP cost and schedule. To help manage a GMP contract, the Owner may create another separate contract with a Construction Manager (CM) [13] or rely on internal staff to perform CM responsibilities. On this project, the Owner developed its own CM staff for construction review processes. In this paper, they are referenced as CM.

The AHJ reviewing the progress of construction against the permitted design documents is referenced as the inspector of record (IOR) [14], who, working for the Owner, performs inspections and signs-off the project's completed work. The IOR uses the AOR's permitted documents (including incorporated COs) to perform their inspections.

This CO review process is shown in Figure 1. The AOR provides design changes to the CM; the CM completes an internal estimate of the cost and time impact, approves those changes, and submits the changes to the GC for pricing. The GC sends the approved changes to their Trades for pricing. The Trades return their estimated cost and time impact, back to the GC, who, in turn, reviews, approves, adds their markup, and submits the total change impact back to the CM, who reviews, approves/rejects/negotiates, and sends to the Owner for inclusion in the Contract.

Figure 1

Year Four of Nine

We began our involvement in the project to assess the impact of the CO process. Our review found that four years into the project, there were unreconciled COs totaling $150m (see table 1). Our breakdown found that the disputes were categorized as follows-

1. Contract/CO overlap. In this dispute, the CO was rejected because the CM disagreed with the scope, identifying the majority was already captured in the GMP.
2. Scope disagreement. CO rejected because GC/Trades and CM disagreed on scope impact.
3. Re-coordination. CO rejected as CM believed re-coordination was "means and methods", already included in GMP.

Time is more than money.

The monthly progress payment process became the focus of our next CO review metric. Monthly progress payments are based on the GC/Trades' completion of work shown against their submitted schedule of values (SOV) [15]. The SOV is submitted at the beginning of the project and delineates the total costs for the Trade and self-performed work by the GC. COs cost and schedule impacts are added to the SOV. Monthly progress invoices are submitted by the GC outlining the projected percentage complete. The CM reviews the percentages against the in-field completed work, approving, or disputing the percentages. As only approved COs are included in the pay application, the GC/Trades internally tracked their ongoing disputed CO costs, adding the ongoing dispute numbers shown in table 1.

Additionally, the GC/Trades progress percentages were typically reduced each month by the CM team. Table 2 shows the monthly reductions. These system effects were adding additional month-over-month unreconciled costs to the project.

Additionally, the disputes were also impacting the project's schedule. The hospital was being built to fulfill California's 2030 state seismic requirements [16]. The project had been in planning for over 15 years and was a part of the system's $5b improvement program and was planned to receive patients in late-2017 to enable the decommissioning and upgrading of existing facilities. If not complete by the beginning of 2018, the system's budgeting office predicted a shortfall of almost $1m a day, just three years away from our start in the project. This per diem penalty included loss of revenue caused by unavailable upgrades for planned procedures only available in the new hospital. Our review shows in figures 2-4 that CO and monthly pay application schedule impacts, if not resolved, would delay the completion of the hospital past 2020. See figure 5.

Literature Review

Ordered Systems versus Complex Adaptive Systems

Centralized controls manage ordered systems, like manufacturing. The workers, acting as agents in an ordered system, are assigned roles and activities through a centralized control system to support assembly-line precision. Managing change within an ordered system is achieved through planning and integration into the product or assembly line. The traditional CO process envisions such a process. However, large multi-year design and construction projects become dynamic systems, with agent churn, unforeseen situational change events. These activities quickly add dynamic disorder to a planned system.

In his 2015 book, A Crude Look at the Whole [18], John Miller writes, "agents adapt in these complex systems, probabilities govern their adaptations…" Complex systems science challenges the notion that understanding a system comes from reducing activities to their simplest components. Miller describes controlled, centralized systems as a product of modern management processes, driven by reducing activities into smaller and smaller “controllable pieces,” rather than “whole-system adaption.” Accepting that complex systems are random and heterogenous allows agent understanding of loss of control. “Creating an effective decentralized decision-making process may be one of the best new old ideas to emerge from complex systems.”

Bernard Aritua, Nigel J. Smith, and Denise Bower define a complex system as one which has -

1. Large numbers of dynamically interacting agents and elements.
2. System openness, with undefined boundaries.
3. Elements in the system are unaware of the entirety of the system’s behavior and respond only to what is available or known locally.
4. System history. Memories and actions are shared and replicated between agents and activities.
5. Agent churn. Agents are added and subtracted. As a result, existing agents become engaged and disengaged throughout the system’s life cycle.
6. The system relies on agent social dependence and feedback loops reinforced through human interaction and behavior. [17]

This is further delineated at an organizational level by Mittleton and Kelly [18], with a comparison of the similarities of a design and construction project and a CAS shown in Table 3.

Table 3 - Characteristics of a CAS and Design and Construction Projects (Mittleton-Kelly, 2003)

As the front-line staff adapts to the system’s randomness, they deploy distributed and situational decision-making, creating additional misalignment and disorder [19]. These front-line agents begin negotiating as individuals and groups, rather than relying centralized controls.

Guiding a Complex Adaptive System

These new project teams must choose the requirements of top-down controls or accepting the localized project needs. This results in behavior that Liang, An, Yang, and Huang describe in *Contrarian Behavior in a Complex Adaptive Systems* [20] where agents-

1. ***defy*** existing top-down controls in a **positive** response to ***local project needs.*** Or-
2. ***adhere*** to existing project controls in a **negative** response to ***local project needs.***

Management may recognize this behavior, adjust their controls to reward and reinforce agent adaption. Rammel et al. [21] recommend developing processes that allow the system and its agents to emerge and co-evolve with the project's needs.

Lean Construction and Last Planner Systems.

Organizations develop tools to manage disorder in ordered systems, creating a *flexible* workforce through cross-training to adapt to an ordered system. For example, Toyota developed the Toyota Production System (TPS) [22], redesigning factory assembly lines to do this. TPS has been replicated in numerous manufacturing systems and is now known as Lean [23].

However, in design and construction projects, it is difficult to cross-train the front-line workers. The plumbers cannot be electricians, electricians cannot be framers and drywallers, and the flooring trades cannot perform framing and drywall work. Furthermore, the professional liability requirements of the AOR and GC/Trades require separation of roles [24]. Workers are the inflexible agent inputs, requiring the system and project to become flexible.

The Lean Construction Institute (LCI) [25] created The Last Planner System® (LPS) [26], to address this inflexibility, assigning the role of *Last-Planner* to superintendents or job captains. These *last planners* are empowered to revise schedule to support the front-line worker's needs. LPS utilizes pull planning processes [27], which plan backward from a task or project's scheduled completion date, and "pull" all activities and tasks to meet the end date, developing bi-directional feedback loops, identifying the tasks and handoffs between all agents in the plan -AOR, GC/Trades, IORs. This plan is flexible and adaptable, continuously updated throughout the project lifecycle, utilizing daily check-ins and lookaheads, until the planned activity (and project) is completed. The LPS implements agent social pressure, utilizing team commitments as promises measured by *Percent Planned Complete* (PPC) [28], which calculate the *"promised to complete work*."

Holonic Emergence and Self-Organization

As the front-line agents adapt to their individual, group, and project needs, they must still attend to their incumbent leadership domain requirements. This causes the agents to bifurcate into two roles - one where they serve the project and their team members, and another as they maintain their organizational reporting requirements. This dual adaptive and reporting behavior is expected by agents participating in a CAS and described as *Holons*.

Holons, delineated by Author Koestler in his book <u>Ghost in the Machine</u> [29], are sagents who emerge and self-organize in an adaptive response to required project tasks. Holons fulfill and support their individual and group needs while maintaining their larger organizational roles.

Naticchia, Carbonari, and Vaccanni [30] describe project-based holonic control systems, where Holons are allowed to independently design and manage project activities. Zekavat, Moon, and Bernold describe similar systems [31], which where Holons self-design and guide project management systems.

Valckenaers and Van Brussel describe manufacturing systems that utilize the adaptive ability of holonic emergence and behavior to control system processes[32]. Holons are key to operating Industry 4.0 [33] enabled systems. In these systems, holons are independent, autonomous units, given agency to plan and act on projects with minimal interference, entrusted to adjust as necessary to guide the project's requirements.

Co-Location and Social Network Systems

Social network systems (SNS) [34] also guide Holons. As more agents join the project, they become Holons - 1) cooperating to fulfill the project needs and 2) balancing those needs with their leadership and contract requirements.

Co-location [32] promotes the collaborative social networks on a project. A Co-located physical space is often called the Big-Room [35], and allows the project's Holons as shared space to work together. The Big-Room's activities typically begin during pre-construction and continue into construction and project close-out. The big room becomes an Oobeya space [36] learning platform where the Owner, AOR and CM, GC/Trades and IOR share their domain and project knowledge. A Big-Room/Oobeya exists throughout the construction lifecycle and can also be used to help the Owner's Facilities team understand how the building they will be receiving will function and be managed.

Human Niche-Constructors and Temporary Work

Design and construction Holons are also engaging in human niche-constructor (HNC) [37] behavior, responding to their evolutionary need to socially band together to modify nature through intentionally constructed environments. The activities of HNC have created distributed and diverse human niches around the planet.

Research Question

Hypothesis

As a result of the Case Study One research and literature review describing construction projects as complex adaptive systems and the emergence of socially connected holonic teams, who need to build as Niche-Constructors, we outline the Research Question.

Construction projects become CAS that cannot be managed with traditional top-down, centralized project controls. The project's agents become Holons with agency to understand, adapt and respond to the project's requirements.

Do traditional construction project controls thwart the human need to build, creating an industry that is inefficient and unproductive?"

Methodology

Building a Holonic Support Framework

Where we identify the methodology used to test the Research Question.

As a member of the CM team, we developed a root cause review of the ongoing CO negotiation and progress payment disputes. In our first meetings with the GC, we were shown $44.4 million in disputed costs and 114 days of disputed schedule delays (See Table 2)

Table 1.

Reimbursable Time and Materials

We would begin the process by modifying the project's existing Time and Material (T&M) system as follows-

1. Begin in the back office of the project, the onsite trailers, which would utilize the project's existing Big Room/Oobeya team engagement.
2. Once a CO was coordinated and detailed in the shared construction models, the CO would move into the field for installation and inspection.
3. We agreed to register every CO with a unique Cost Issue (CI) number, enabling all team members, not just the CG and Trades, but also the AOR, IORs, and our CM team, to charge to the CI. This would allow a capturing of all costs to capture the entirety of the impact of the CO. Progress payments would be made throughout the CO cycle, using the CI unique identifier.
4. All work would be validated through observations, model review during design and coordination, and infield during installation and inspection. This would enable a feedback loop with end-to-end tracking that would validate the *Total Cost* of the CO, which could help reconcile the disputed COs.

The system requires streamlining the existing GC, Trade, and AOR project billing and account payables systems. For the T&M CO program, a centralized tracking system was created to enable the real-time collection of labor and materials as the work was being completed.

Part 2

Where we outline the deployment of that methodology. We include metrics, what was deployed, how it was deployed, and what happened.

Don't call us Holons

Some notes on terminology.

While applying the methodology, we were conscious of the Hawthorne Effect [38], which describes the activities of agents aware of their participation in a study modify their behavior accordingly. Therefore, we continued to use the construction industry terms for the adapting processes.

1. Workers/Crews, not Holons/Holonic Teams. When we started the project, we recognized that the individual front-line agents were already exhibiting holonic behavior by gathering into temporary groups for coordination and installation tasks. Rather than calling these groups out as holons, we maintained the use of existing construction terminology referencing the workers as Foreman, Journeyman, Apprentice, and Laborer [39]. These experience-related roles did not determine the roles the agents played as holons. A Foreman or Journeyman could, and did, perform similar roles as members of the holonic teams shown below-
    a. Coordinating Holons – Holonic team of the CM and GC/Trade PMs and Foremen to ensure work was identified, tracked, and paid.
    b. Scheduling Holons – GC/Trade PMs and Foremen, Identify the work that needs to be done, and schedule with the workers/crew, based on Last Planner roles.
    c. Worker Holons - Front-line staff of workers and crew-including onsite AOR staff for decision-making. This staff performed design sketches, coordination, and construction.
    d. Inspection Holons – GC/Trade QC PMs and IORs Inspecting and approving the work.
    e. Payment Holons – CM/GC/Trade PMs, ensure tickets are signed, turned in, and paid
2. The Big-Room, not Oobeya Space. Our field trailers functioned as co-located offices and meeting rooms for all team members. This space included the necessary internet and servers, monitors, meeting rooms, etc., and offices or hoteling space. Other project team members came into the trailers for coordination and OAC [40] meetings. We formalized the learning occurring during the CO/CO review meetings. But did not call the space an Oobeya.

Formalizing Change Review through a Triage Platform.

RFI Triage Meetings

Triage [41] describes the sorting of tasks according to urgency. We used the term to sort RFIs by urgency, creating a weekly Triage T&M meeting (See Figure x), during which each closed RFI would be "Triaged", with the GC/Trades, CM, and AOR reviewing the project impact. Each impact would be reviewed, negotiated, coordinated, and approved during the meeting. A CI was created, schedule reviewed, and the Trades would continue the work they started with the initial review of the RFI, continuing coordination in the trailer and onto installation in the field.

Figure x

Inspection Software

We augmented the project's existing in-field inspection cloud-based software application, which also housed the project's floor plans and inspection requests. We added the approved CO/RFI documents, and CI numbers, and time-keeping module, allowing each holon to use the system to post their hours and material costs to the CI number.

Integrating Design Holons into the in-field teams

The AOR and their teams are required throughout the construction phase of a project, typically already charging their time to construction administration T&M [42]. We added them to the inspection time-keeping program and began tracking their time to a CI number as well.

Promoting social networks for the project's niche-constructors

Our research question pursued a methodology that would recognize and support workers as Holons, but also their roles as niche constructors, recognizing and rewarding their role as creators of new built environments. In this role they were more than builders, they were delegates for the project and the current and future users, representing our need to build, actively shaping an environment in which all humans participate as users.

Furthermore, due to the system's dynamics [43], at work within the CAS, the entire regional healthcare system and supply chain would be affected by their efforts. As happens in all dynamic CAS, our holons were building more than just a hospital; they were facilitating changes to the delivery of healthcare services. This was reinforced in one instance, where a CM holon's daughter was planning for surgery to adjust her hip rotation due to existing titanium previously inserted in her fractured femur. The GC/Trade holons were building the OR where future operations would take place, which would enable a more precise procedure with image-guided equipment [44]. This team member reminded the teams of the value and urgency of their work.

The Triage T&M also rewarded the Trade, GC, and AOR domain leadership for their support for the system, ensuring that their reasonable CO estimates were 1) reviewed, 2) approved, and paid as quickly as possible.

Analyze results of the deployment of the Methodology of Case Study Two

Development of Holonic teams

We utilized and leveraged the existing holonic teams developed during the Oobeya/Big Room design-assist pre-construction efforts. These teams weren't formally recognized by the project management. The Triage T&M process produced an opportunity to acknowledge and formalize these holons. The results of Case Study Two measured against Case Study One are shown in Table x.

Table x

The traditional CO controls processes in Case Study One were administered by the owner's CM team who were not working side by side with the front-line staff. This unequal stratification of control results from in a false "tragic necessity" [53], which is identified as a requirement to mitigate bad decision-making in large capital-intense, risk-averse projects.

The results of our two case studies, though limited, show this requirement to be false. The findings from case study one show that the project's top-down controls for the change request (CO) process had a continuous building negative effect on project productivity and efficiency, adding multiple delay and cost impacts. Traditional project controls "regard cost overruns and delays as ***types*** of risks"; however, "both cost overruns and delays are ***consequences*** of other risks which occur because of other internal or external factors" [46].

These factors included three items-

1) the multiple and recurring layers of review,

2) the ongoing disputes over proposed cost and schedule impact, and

3) month-over-month reductions in pay applications.

With the Triage T&M program, the in-field Holons were given project agency to review and approve COs, and to develop the cost and schedule analysis, incorporate design, coordination, detailing, installation, completion, and inspection of the work.

Contribution of this Case Study to the body of knowledge on design and construction controls procedures

Front-line agents in CAS self-organize into Holons, working together to understand, shape, and guide the system. The system and holons adapt together. Traditional top-down controls inhibit this adaptation. Contracting methodologies like Design-Build and Integrated Project Delivery create less hierarchical teams, but they require fundamental contractual changes for the Owner, AOR, GC/Trades.

The Triage T&M program facilitated and guided the development of holons into systems of front-line design and construction support without modifying the existing contract.

Conclusion and Next Steps for the Research and Methodology.

This section presents the results of a simple but significant shift in CO processes enabled and harness self-organizing teams' creative project powers while maintaining their required responsibility to their companies and organizations.

The Triage T&M program's use of CIs enabled real-time tracking of team costs. As a result, several Trades incorporated their remaining contract work onto a unique T&M CI number for completion tracking, eliminating their portion of the monthly percentage pay application review. This is an opportunity to use existing T&M models for discrete tasks and break out sections of the contracted work to track as a separate T&M allowance. Since T&M processes were already used on the project for discrete tasks, and the AOR was already deployed under a similar T&M program, leveraging the CI tracking feature of the Triage T&M, created a formal review process for all work.

And as a separately funded allowance, the Triage T&M program de-linked COs from the project's traditional controls without sacrificing contracted oversight. The payment holons ensured this through the required ticket exchanges. And once the GC/Trade leadership began receiving immediate payments from the program, the resulting cash flow enabled support for all remaining contract work to be tracked through Triage T&M, eliminating future pay application negotiations, and a validation tool to reconcile past disputed COs.

The Value of Incentives in Guiding a Complex Adaptive System

We also found as Rouse writes in *Health Care as a Complex Adaptive System: Implications for Design and Management* [47], that "the best way to approach the management of complex adaptive systems (was by) adopting a **human-centered** perspective that addresses the abilities, limitations, and inclinations of all stakeholders," and, "the management approach should emphasize leadership —influence rather than power." "No one can require that stakeholders comply with organizational dictates. *They must have incentives to behave appropriately.*" The recognition and harnessing of holons, combined with prompt leadership affirmation of their decision-making, rewarded with payment, reinforced the *self-organizing and governance* of the holonic teams.

Developmental Niche Constructors- The Humans Need To Build

Winston Churchill stated, "We shape our buildings, and afterward our buildings shape us," [48], describing the co-evolution of builders and their environments. We argue that the *need to build* is a singular force driving Maslow's foundational hierarchal needs of Physiological, Safety, Love, and Belonging [49]. Needs that can only be attained through the creation of buildings, either as consumers of built environments or through interactive construction to provide for that consumption. Centralized, top-down controls inhibit this need, interrupting the cultural and social need for humans to adaptively work together in response to shape a more sustainable environment.

Apprenticeship and Learning

Apprentice as teaching is key to design construction activities. As Kim Sterelny writes in From Hominins to Humans: how Sapiens became behaviorally modern, [50] “apprentice learning is a very powerful mode of social learning, making possible the reliable acquisition of complex and difficult skills. It is learning by doing. But it is learning by doing in an environment seeded with informational resources. Moreover, there are many opportunities to learn by observing highly skilled practitioners. Apprentice learning identifies a form of learning that can be assembled incrementally, and once established, it brings selective cognitive and social changes that increase the reliability and reduce the cost of learning. Apprentice-based training is distributed, neutral, and inclusive.

Next Steps

We showed in this paper that decentralized controls, distributed through the front-line staff, enable the development of Holons in complex systems.

The success of the CO Triage T&M program allowed all remaining contract work to move to the Planning and Payment platform. The traditional control systems of SOVs and Monthly Pay Applications can be disrupted through T&M tracking against the SOV, which would streamline the monthly review and approval process. The CM and AOR teams could review GC/Trades construction progress against the inspection module in real-time. While this process wouldn’t eliminate estimates and negotiations, it would automate progress tracking. Photogrammetry and Lidar [51] are now used for completion tracking and as-builts. These systems could be combined into verifying the daily progress, automatically updating the progress percentage. Sensors and other tagging devices could be used to drive the weekly lookaheads for planning, facilitating the movement of holonic teams throughout the project as work and material is made available, and when to adjust the direction of movement, due to site conditions. This system would allow the teams to adapt accordingly.

As the Trades do most of the work, they are the most at risk for payment disputes and delays. Design and construction is a “pay when paid” [52] work environment for the Trade organizations. When a Trade invoice is submitted and approved by the GC, it rolls up into the GC’s invoice (hence the monthly pay application). After the Owner approves the invoice, it may take up to 90 days for the GC to receive payment. The GC may be allowed another 90 days to pay the Trades. The lag between completing the work and receiving payment may be up to 200 days or longer. Since the front-line staff are employees who are paid bi-weekly or monthly, whether the Trade is paid or not, the carrying burden of delayed payment rests solely on the Trades. Research shows that in 2019 the burden in the US was estimated to be $64 billion [53]. The T&M Triage program eliminated the monthly pay app negotiation, ensuring that the GC was paid within 30 days. The GC then turned around payment to the Trades within 30 days of their receipt of payment. The 200 days were compressed down to 60 days.

Hesam Hamledari and the Center for Integrated Facility Engineering (CIFE) [54] have researched how blockchain and smart contracts streamline trade payments. In *Measuring the impact of blockchain and smart contracts on construction supply chain visibility* [55], processes are identified which create direct Trade payments. Holons could be included in this system, directly receiving payments for their completed work.

Distributed Autonomous Organizations (DAO) [56] could be the next step in holonic design and construction teams, facilitating the flattening of contracting, work, and payment systems. DAOs have are currently used for learning environments [57], which could be transitioned to a project’s Big-Room/Oobeya space.

Conclusion

These two case studies demonstrated the role that traditional top-down hierarchical project controls play in exacerbating construction change management processes. We created a new change management framework within the contract through an innovative T&M platform, including new documentation, communication, and payment processes. The platform utilized existing holonic teams for distributed decision-making, expediting the time from design to the payment process and minimizing the CO negotiation process. The platform and processes were soon used to incorporate and monitor the builder's remaining contract work to assist in project completion. In addition, the platform did not require adjusting the project's existing contract terms, demonstrating that it can be applied to traditional design-bid-build design and construction projects.

Recognizing and rewarding holonic teams validated their role as niche-constructors, following their evolutionary need to build. creating processes and systems that acknowledge this need either as creators or consumers of built environments proves the connectedness of humans to their built environments, which can be used to generate a greater understanding of humanity's role in building.

-End-

Figures

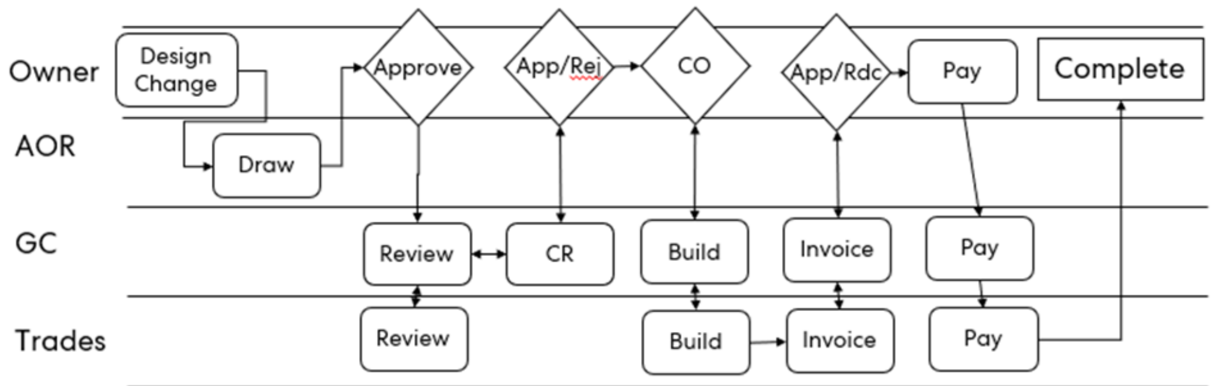

Figure 1

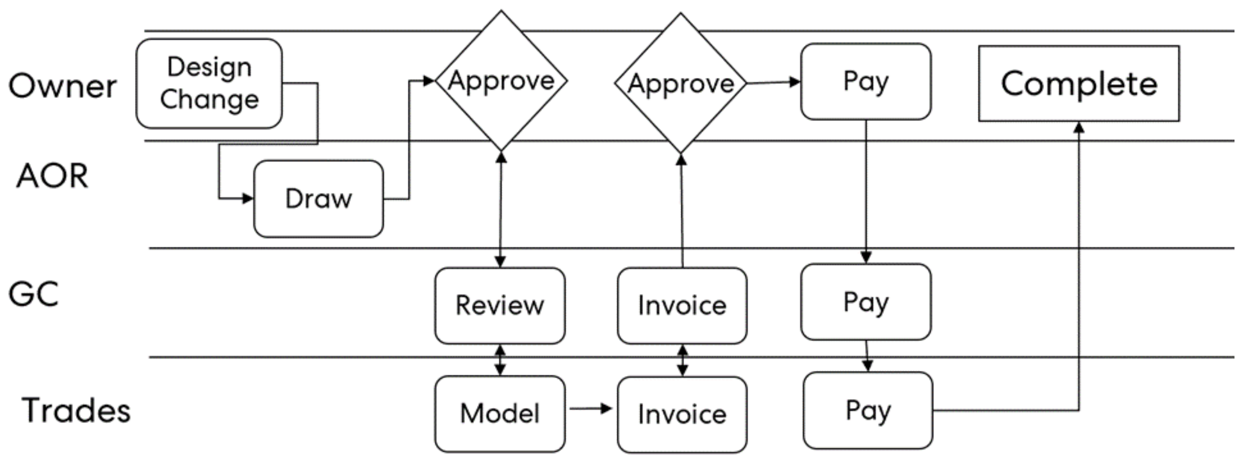

Figure 2

Tables

Complex Adaptive System Condition	**Design and Construction Project**
Large number of dynamically interacting elements	Multi-Disciplinary workers on site
Elements contain sub-elements that affect each other	Multiple high and sub-level agents
Non-Linear interactions. Small changes cause large effects	Deliveries missed. New and absent workers
Interaction nearby agents modulate behavior	Multiple exising and new agents
Overall behavior not predicted by individual agent behavior	Incomplete system work
System is open with undefined boundary effects	Uplanned daily jobsite activities
No equilibrium. Inputs required to maintain organization	Material shortages, delivery issues
System has history. Agents remember past for current behavior	$$m Change Orders Owed/Lost Time
Elements ignorant of behavior of system as a whole	"only responsible for my work, my area"

Table 1

Change	**GC $$m**	**GC Days**	**CM $$m**	**CM Days**	**Diff $$m**	**Diff Days**
Radiology	$ 57.8	94	$ 42.3	88	**$ (15.5)**	**-6**
CT Scan	$ 83.0	108	$ 72.0	67	**$ (11.0)**	**-41**
ED Changes	$ 23.0	35	$ 18.0	22	**$ (5.0)**	**-13**
Pharmacy	$ 66.9	129	$ 54.0	75	**$ (12.9)**	**-54**
Total	**$ 230.7**	**366**	**$ 186.3**	**252**	**$ (44.4)**	**-114**

Table 2

	Case Study 1	**Case Study 2**
CR Review Time - Days- (Avg)	**66**	**12**
Cost Dispute -%- (Avg)	**8**	**4**
Day Dispute -%- (Avg)	**7**	**2**
Payment Time -Days- (Avg)	**140**	**60**

Table 3

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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