# Construction Project Management Analysis of the Kaven Hall Renovation

A Major Qualifying Project Report submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
Degree of Bachelor of Science

in
Civil Engineering

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Report Submitted to:
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# Acknowledgements

The project team would like to thank our advisor Professor Jessica Rosewitz for advising this project. The team would like to thank the entire Kaven Hall Renovation Team at Consigli Construction Company, Stantec, and KVA for their hospitality in allowing us access to the site and project meetings and their eagerness to help teach us as the next generation of construction professionals. The support, trust, and generosity of Nicholas Palumbo and Ron O'Brien from WPI Facilities cannot be understated. Lastly, we would like to thank members of the Civil Environmental and Architectural Engineering Department for agreeing to share their thoughts, experiences, and expertise related to the Kaven Hall Renovation with us. It is our hope that this is the start to a prosperous future of Construction Project Management MQPs.

# Abstract

This project analyzed the 2021-2022 renovation of Kaven Hall which occurred in a dynamic environment with variables such as unforeseen impacts, a pandemic, and supply chain issues. Constructed in 1954, Kaven Hall is home to an ever-growing department with many areas of study. With an increasing demand on the aging building, a renovation needed to occur. Both student MQPs and WPI Facilities studied possible renovations or replacement of the building. Several updates were made in 1979 and 2000, but none addressed ADA compliance until 2021. Its location in WPI's de-facto historical district and unclear pre-existing conditions complicated planned work. The project's conflict resolution methods, project management, and use of construction technology were studied. The outcomes were used to create recommendations for future renovation projects.

# Capstone Design Statement

All students attending ABET (Accreditation Board for Engineering and Technology) accredited engineering programs must complete a senior capstone design project prior to receiving their degree. The purpose of a Capstone Design Experience is for students to apply their cumulative knowledge learned in previous courses and projects during their undergraduate education towards the successful completion of a design experience consisting of appropriate engineering standards and multiple realistic constraints. The Capstone Design Requirement at Worcester Polytechnic Institute is met through the MQP (Major Qualifying Project).

This MQP involves the analysis of a real-world renovation project through the application of Construction Project Management principles, technology, engineering economics, interaction with project stakeholders, and professional practice. The end goal of creating recommendations for future renovation projects was achieved.

Past project proposals were researched and analyzed utilizing engineering economics. The concept of present and future value was exercised. The student team was familiarized with industry metrics such as CCI (Construction Cost Index), MCI (Material Cost Indexes), LCI (Labor Cost Index) and how they affected the cost of construction. Reasonable assumptions such as correcting past estimates to account for labor were exercised to achieve more realistic costs for comparison.

Under the guidance of construction professionals, the student team learned about daily site operations and attended official (OAC) Owner, Architect, Contractor meetings. Meeting minutes, schedules, and other documentation were analyzed for problematic items that could impact project schedule, cost or client satisfaction. Lessons learned in coursework and during the project were quickly put to the test on site visits.

# Licensure Statement

The NCEES (National Council of Examiners for Engineering and Surveying administers the evaluation process for PE (Professional Engineering) Licensure within the United States. The goal of this is to ensure that all engineers are held to the same high standard of competency before they embark on work that others health and safety lies in the balance of. Professional Engineers are granted the weight and privilege of stamping and approving engineering plans. In essence, their professional judgement holds the responsibility of the work of all junior engineers and staff who may have contributed towards those plans.

The first step in gaining this authority and responsibility is the successful graduation from a four-year ABET accredited engineering program or suitable experience. However, some states stipulate that there is no substitute for a degree from an ABET accredited program. After graduation, the FE (Fundamentals of Engineering) exam must be passed. Upon passing, the individual earns the title of “Engineer in Training”. The NSPE (National Society of Professional Engineers) states that they must work under the direct supervision of a licensed PE for 4 years and be exposed to multiple facets of the engineering career. During this time, a candidate develops a portfolio of work which is to be presented to a state PE board for approval. Once approved, the candidate may sit for their state’s PE exam. When the individual has passed the PE exam, they are expected to continue to further their knowledge in the field and mentor young engineers. Developing professional skills and continued education are the requirements for retaining the PE license. A PE license opens up avenues for professional development or starting a private engineering practice.

# Authorship

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| Construction Project Management Analysis of the Kaven Hall Renovation | |
| Acknowledgements | Joe |
| Abstract | Joe |
| Capstone Design Statement | Joe |
| Licensure Statement | Joe |
| Authorship | |
| List of Figures | |
| List of Tables | |
| Executive Summary | All |
| 1.0 Introduction | |
| 2.0 Background | |
| 2.1 Review of Past Kaven Hall MQPs | Joe |
| 2.2 Project Personnel Biographies | |
| 2.2.1 Owners | Igor |
| 2.2.2 Designer - Stantec | Joe + Igor |
| 2.2.3 Consigli | Igor |
| 2.2.4 Project Manager | Igor |
| 2.2.5 Project Executive – Jody Staruk | Igor |
| 2.2.6 Project Superintendent - Stephen Price | Joe |
| 2.3 Interviews | |
| 2.3.1 Faculty | Joe |
| 2.3.2 Project Team | Joe |
| 2.3.3 Owner | Igor |
| 2.3.4 Contractor | Igor |
| 2.4 Procore | Igor |
| 2.5 Pandemic Impacts | Joe |
| 2.5.1 The Early Pandemic | |
| 2.5.2 Lasting Effects | |
| 2.6 Contract Structure | Igor |
| 2.6.1 Negotiated Contracts | |
| 2.6.2 Cost Plus Contracts | |
| 2.6.3 Design Build contracts | |
| 2.6.4 Design Bid Build | |
| 2.6.5 Construction Management at Risk Contracts | |
| 3.0 Methodology | |
| 3.1 Project Familiarization | Igor |
| 3.2 Project Documentation Research | Igor |
| 3.3 Identification of Problematic Items | Igor |
| 3.4 Select Problematic Items | Igor |
| 3.5 Analyze Project Problem Solving Methods | Joe |
| 3.6 Develop Construction Management Recommendations | Joe |
| 4.0 Results – Project Management Review | |
| 4.1 Literature Review | Igor |

# List of Figures



# List of Tables

# Executive Summary

## Introduction

This project analyzed the 2021-2022 renovation of Kaven Hall which occurred in a dynamic environment with variables such as unforeseen impacts, a pandemic, and supply chain issues. Built in 1954, it is home to an ever-growing department with many areas of study. Student Major Qualifying Project (MQP) groups and WPI Facilities have evaluated a variety of renovation options for the building since 1999. Several updates were made beginning in 1980 but none addressed ADA compliance until 2021 by a team from Stantec, Consigli, and KVA. The renovation project's conflict resolution methods, project management (PM), and use of construction technology were studied. The strengths and weaknesses of these methods as well as key sticking points were used to create recommendations for future renovation projects.

## Goal and Methodology

The goal of the project was to develop a set of recommendations that identified best practices for historic renovations to mitigate potential scope creep and cost overruns while delivering a project on time and within budget that exceeds client satisfaction.

The project was accomplished with six main objectives. (1) Renovation Project Familiarization which required accompanying the professional team in weekly Owner, Architect, Contractor (OAC) meetings and site walks to create first-hand documentation of the project. Interviews were conducted with key project personnel and stakeholders to gain an understanding of the project and to better define the original scope. (2) Project Documentation Research involved accessing files within Procore, requesting previous proposal documents, and cost estimates. (3) Problematic Item Identification screened OAC meeting minutes, notes taken, schedules, and interviews for problematic items. (4) Problematic Item Selection involved the analysis of problematic items from both the renovation and case studies for schedule and cost implications. (5) Project Management Review analyzed performance, schedule, budget, problem-solving techniques, and tools utilized. (6) Construction Management Recommendations were developed utilizing observations from both case studies and the PM review.

## Results and Analysis

The Construction Manager at Risk with a Guaranteed Maximum Price was determined as the best contract and project delivery method to address all Kaven Hall project-specific factors. This contract let WPI select their preferred contractor that provided additional professional expertise. The GMP established a price ceiling and set aside funds for allowances and contingencies. Since all renovation tasks were built on pre-existing conditions, reserving funds for problems that arose throughout the lifetime of the project accelerated the problem resolution process.

The literature review provided the project team with information on problems commonly encountered during renovations and recommendations for mitigation. This research provided insight into which Kaven Hall problems were common in other renovations and which were specific to Kaven Hall. It also provided several renovation recommendations that the project team analyzed and compared to the solutions witnessed during the Kaven Hall project. Developing a list of problems and recommendations allowed the project team to identify gaps in the recommendations and create a comprehensive list of recommendations that will be useful for future projects.

Technology such as LiDAR scanning, ground-penetrating radar, and BIM were used to enable later work. However, these tools were not used to their full potential and were confined to items identified in the original scope. Several shortcomings on this project could be attributed to either failure to maintain an active BIM model, inadequate data, or neglect to utilize the model fully.

A concern was that ordering more detailed LiDAR scans and surveys of existing conditions would not result in worthwhile savings. While it is not feasible to complete an exhaustively detailed survey, more attention could be put towards historically problematic areas where existing knowledge of the building is lacking. As an example, it was later discovered that the above-ceiling heights in several rooms were not to code and needed to be reworked. If discovered earlier, the ceiling could have been specified to be replaced or fitted with proper fire suppression coverage.

Coordinating the use of the BIM model with project personnel or subconsultants with knowledge of fire protection design could also have benefitted the project. This project faced several issues that involved compliance with fire codes. A large component of this was attributed to the existing fire suppression system and coverage. MEP clash detection was successfully utilized in earlier work on the project, but to a lesser extent on added scope items. The BIM model could have been better used for quantity takeoffs for the project.

ProCore was the information management system used by Consigli throughout the Kaven Hall project that increased efficiency with improved communication and automatic data organization in a centralized location. This program specifically streamlined the Request for Information (RFI), Submittal, and Punch List process. The same ProCore features that facilitated these processes made the Schedule tool unusable. Schedule changes automatically notify all parties. Frequent schedule changes cause overcommunication that makes it difficult to identify the most recent and causes confusion. Therefore, the ProCore capabilities that streamlined the RFI, Submittal, and Punch List process also made it disadvantageous to upload a constantly changing schedule.

## Conclusion

While the professional project team adapted and responded well to the pandemic impacts, unforeseen conditions, and growing project scope, the Certificate of Occupancy was not issued as expected. A result of material shortages that led to difficulties getting ahold of the equipment including the Fire Panel Annunciator, a non-code requirement requested by the Worcester Fire Department later in the project. Proactive PM decisions in response to pandemic impacts such as selecting alternatives when possible, and the early purchase and storage of materials and equipment aided in preserving the project schedule and cost. A growing scope was expected due to unforeseen conditions common in renovations. These were addressed with a contract that reserved funds to address issues discovered along the way while guaranteeing a maximum contract value. The analysis of the Kaven Hall renovation project and other case studies led to the creation of recommendations for future work. While the project was completed within budget, there were areas for improvement in terms of schedule and customer satisfaction.

## Recommendations

1. More detailed assessment of building equipment to identify replacement needs before scope setting.
2. Early identification of requests from the Authority Having Jurisdiction that prevent the issuance of the Certificate of Occupancy.
3. Critically weigh the potential risks and rewards of conducting varying levels of site investigation.
4. Incorporate trades in the iterative design process to address constructability issues.
5. Use the BIM model to better anticipate quantitative data on the project and to coordinate with personnel/subconsultants with knowledge of code compliance.
6. Identify requirements for functional lab usage and reevaluate the feasibility of early turnover if requirements cannot be met.
7. Early identification of inter-building utility constraints.

# Table of Contents

# 1.0 Introduction

Kaven Hall, located at the corners of Boynton and Salisbury Streets in Worcester, MA, has served as a home to Worcester Polytechnic Institute's Civil and Environmental Engineering Department since its construction in 1954 and as of 10 years ago, the Architectural Engineering Department (now CEAE). Throughout the years, Kaven Hall has received incremental updates such as lab space and equipment updates. The largest of these projects was the $350-$400,000 renovation and re-equipping of the labs which included spaces such as the student lounge and the main lecture hall in Kaven Hall 116 from 1979-1980 [1]. However, large issues such as compliance with the Americans with Disabilities Act of 1990 (ADA) had not been addressed. This was likely due to budgetary and scope related constraints at the time of earlier renovations. Additionally, as the act hadn't been established, there was no legal obligation to install an elevator or other accessibility features at the time. From May 2021 to February 2022, an extensive renovation project was undertaken with the goal of creating a Kaven Hall that meets the current and future needs of WPI while preserving the past.

Kaven Hall posed a challenge to renovate due to its lack of definitive knowledge of existing conditions. Its age and location within the de-facto historical district of WPI's campus further complicated the matter. Previous student Major Qualifying Projects (MQPs) have highlighted the need for renovation and identified specific steps required to bring the building to current standards such as the inclusion of an elevator for ADA compliance. In addition, past project groups have expressed the difficulty of finding documentation such as as-built plans and layouts. A unique aspect of this project is the task of analyzing an actual renovation that occurred in a dynamic environment with variables such as unknown as-built conditions, a pandemic, and supply chain issues.

The goal of this project was to analyze the 2021-2022 renovation to Kaven Hall and develop a set of guidelines identifying best practices for future renovation projects to mitigate potential scope creep and cost overruns while delivering a project on time and within budget that exceeds client satisfaction. This was achieved through the following steps. (1) Learning about and accompanying the professional team in weekly OAC meetings and site walks to document the process and conducting interviews to fill information gaps and define the scope. (2) Research, collect and review all project documents and communications. (3) Identifying consistently reoccurring problems and items that negatively impacted the cost and schedule. (4) Selecting the most problematic items common to historic renovations and existing structures for an in-depth analysis. (5) Reviewing the methods of resolution used by the professional team to mitigate these common problems and conducting a literature review to identify other possible solutions. (6) Develop a set of construction management guidelines to assist professional teams in anticipating and resolving common renovation problems that may impact the cost and schedule.

# 2.0 Background

Background research was conducted to establish knowledge of the building and the project. Past MQPs and the history of Kaven Hall were researched to understand the longstanding needs for an improved facility. To better understand the project and its operation, interviews of key project personnel were conducted. The project stakeholders (owner, architect, contractor) were also researched. From this information, biographies were developed. Project management topics such as Contract Structure and the projects used of Procore, a document management system, was also researched. The impacts of the COVID-19 pandemic on the construction industry were researched as this project was impacted by it.

## 2.1 Review of Past Kaven Hall MQPs

Throughout the past two decades, WPI students have worked on 8 different academic projects on Kaven Hall. Four projects address renovations, two of those focus on the whole building while the other two focus on the attic only. Two focus on energy analysis of the building or an addition and the remaining project focuses on a ground-up replacement project.

Ranging from topics such as energy efficiency and sustainability to proposed renovations, these student projects demonstrated the longstanding need for improvements to the building. Additionally, the research on existing conditions in many of the projects allowed a detailed look at the building's history and some of the reasons behind the need for such renovation or changes.

Kaven Hall was erected in 1954 and consists of two levels of classrooms and offices, a basement laboratory space, and an attic containing storage and mechanical equipment. Prior to the installation of an elevator in 2021, two main stairwells on the North and South of the building served as the only means to access the three main floors [2]. At the time of its construction, elevators were not standard for buildings of similar height. Due to this and other existing conditions, prior to its 2021 renovation, Kaven Hall was not complaint with the Americans with Disabilities Act of 1990 (ADA). This was be a topic for discussion throughout many of the academic projects [3].

The earliest MQP titled “Renovation of the Kaven Hall Attic” by Corey M. Brodeur, Paul C. Elliot, and Timothy J. Fox was completed in 2003 [2]. This project though highly focused on the attic and a potential reuse scheme, it served as an initial assessment of the building’s condition. A survey completed as part of the MQP by 24 students and 12 faculty members demonstrated that the department wanted improved student study and group work areas, additional offices, and conference rooms. The demand for space outpacing the availability of existing facilities was also emphasized. The proposed work on renovating the attic was projected to take 176 days (35 weeks or 8.75 months) at a cost of $980,000 [2].

A second MQP titled “Renovation of the Kaven Hall Attic” by Chad Farrell, Sean Kennedy, and Elizabeth McLaughlin was completed in 2009 [3]. Both the 2003 and 2009 MQPs emphasized the need for an ADA compliant Kaven Hall which entailed the addition of an elevator. This project obtained a more accurate understanding of the floorplan, roof, mechanical equipment and existing permanent structures. This proposed renovation included an in-depth project schedule and cost estimate. The duration was to be 150 days (30 weeks or 7.5 months) at a cost of $1,820,000 [3].

An MQP titled “Renovation of Kaven Hall” was completed in 2011 by JungMi Kim [4]. This project aided in establishing the initial conditions of the building by including floorplans dating to work performed in 1993. One again, the emphasis was creating an ADA compliant building which entailed the structural design for an elevator. This project proposed a renovation cost of $1,760,000 [4]. A project schedule and duration were not provided. In the project’s recommendations, it was written that the existing structural conditions of the building were not certain, and more research would benefit future work.

The most recent renovation related MQP was titled "Renovation of and Addition to Kaven Hall" was completed in 2014 by Brianna Maljanian and Samantha Meyerhoff [5]. This project designed a new space to be added to the existing building and included means to integrate the two parts. In addition to the Massachusetts Building Code, the project implemented LEED design specifications and performed seismic analysis. An elevator was also included in the design of this project. A projected cost and schedule were also produced. The estimated project duration was 42 weeks or 10.5 months at a cost of $8,500,000 [5]. A suggested start of late March/early April was noted as beneficial as the project would be mobilizing for a start over the summer break. An emphasis was also placed on scheduling construction that minimized disruption of campus activities during the academic year and more intensive tasks to be completed in the summer/breaks. This project also underscored the relatively poorly documented structural condition of Kaven Hall. The group noted that "original or as-built structural drawings and recent architectural drawings could not be found" and that research on this would benefit future work.

In 2015, an architectural engineering MQP titled "Addition to Kaven Hall – Performance-Based Design Using Energy Simulation Tools" by Yan Zhang proposed a 30,779 square foot addition [6]. It was stated that the building was originally constructed for one major but is now occupied by three, thus the need for more space. The site of Kaven Hall and the surrounding areas were researched and documented. A Revit-model of Kaven Hall as it appeared in the 2014-2015 academic years was also created. An interesting aspect of the project's was the inclusion of aspects such as a foot-traffic circulation study and a solar study. These aspects with the addition of deliverable such as architectural renderings provide insight to the perceived wants and needs of the department.

The MQP titled “Energy Retrofit of Kaven Hall with Aerogel Application” by Atoning Wang in 2014 analyses the retrofitting of the building with advanced materials. Focusing on the windows, the case for the use of “Aerogel” is proposed [7]. The project analyzed the energy performance of the building as well as mapping and coding the floor plan by room usage. The relative energy inefficiency of the existing building and its heating/cooling methods was highlighted. The importance of replacing the existing windows was supported by this project.

In contrast to the MQPs that evaluated the potential renovation of Kaven Hall, one from 2018 evaluates the total replacement of the building. The project titled “WPI Replacement to Kaven Hall: Structural Design” by Laurence R Cafaro, Eric Von Schroeder, Nicholas Robert Day, and James Ballou Loring sought to design a floorplan and structural framing design for a replacement to Kaven Hall. This suggests that Kaven Hall be replaced due to the lack of an elevator and the inability of existing classrooms to accommodate increasing class sizes. The estimated cost for the replacement was $7,850,200 for a steel framing option and $9,307,000 for concrete framing [8]. The project duration was estimated to last 10 months.

The past student projects on Kaven Hall provide reasonable background as to why the building should have been renovated. Utilizing this and information to be further gained through research, a timeline and list of wants/needs of the department was generated as seen in Figure 1. Cost and schedule information from these past MQPs will be used to analyze the performance of the current renovation project.

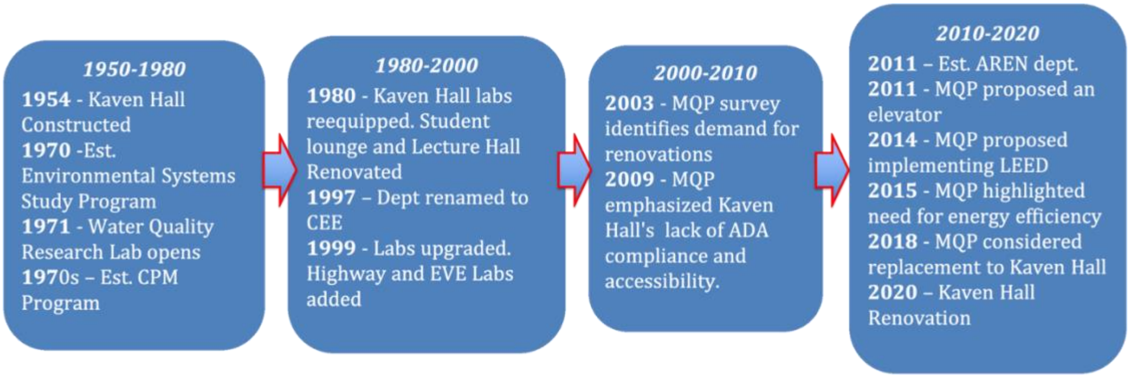


*Figure 1 Timeline of Kaven Hall Milestones and MQPs*

## 2.2 Project Personnel Biographies

Within a construction project, there are typically three key stakeholder parties. The owner, the architect/Engineer (designers), and the (general) contractor. In this project the owner was WPI, the architects/engineers were Stantec and their consultants, and the general contractor was Consigli Construction. Key personnel from these parties were interviewed during this project to gain an understanding of their roles, backgrounds, and what skills they bring to the renovation.

### 2.2.1 Owners

Every project begins with the owner, and their role is crucial in ensuring a successful final product. The principal role of the owner is to set the operational criteria and level of quality for the completed project [9]. This means that they must convey the necessary requirements for the building's intent to the design team. The owner must identify the need for special equipment, materials, or company standards that will apply to the project [9]. The owner is also responsible for clearly defining their own role and level of involvement. This promotes clarity between the design and construction team and allows them to understand the role of each party. The owner must also specify his expectations of the project by setting parameters on total cost, payments of costs, major milestones, and the project completion date [9]. On this project, the role of the owner was primarily carried out by Nick Palumbo and Jeff Lussier. Their roles and responsibilities are detailed below.

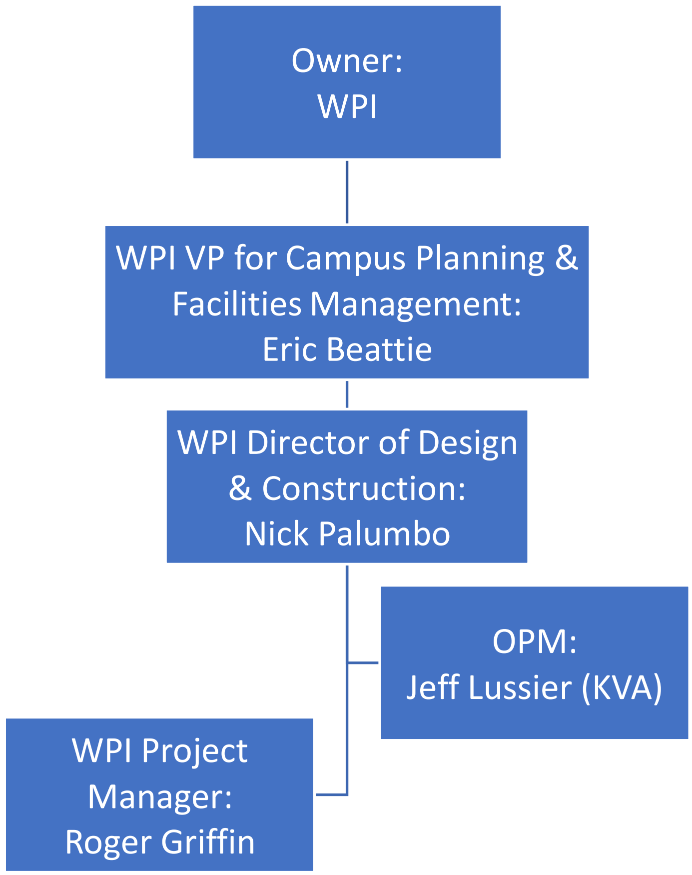


*Figure 2 Kaven Hall Renovation OBS (Organizational Breakdown Structure)*

Nick Palumbo is the Director of Design and Construction at WPI. His role primarily focused on the planning and management of all physical campus changes. He oversees and ensures that the design, construction, renovation, and major maintenance projects are in adherence to the campus master plan [10]. His main responsibilities are to attend project meetings around scope planning, design development, construction estimates, scheduling, and budgeting [11]. He worked closely with faculty and staff to determine overall project requirements, research necessities, schedule requirements and department requests [11]. His experience provides him the tools to achieve all this. Nick has worked at WPI since 2015 as the Facilities Project Manager and recently became the Director of Design and Construction in 2021 [12]. Before working at WPI, he was an Assistant Project Manager for Skanska USA Building Inc. from 2006 to 2015, and he worked as a Field Engineer for RF Walsh Companies Inc. from 2005 to 2006 [12].. This experience allows Nick to contribute and assist with the various difficulties that arise during every project.

Jeff Lussier was contracted by WPI as the owner's project manager (OPM). The general role of an OPM is to act on behalf of the owner to provide impartial advice with no conflicting interest as they oversee the entire project [13]. The OPM is here to monitor not manage the project. This means assisting the PM and preventing problems from occurring like unforeseen construction issues, exceeding construction schedule, and running over budget [14]. In his own words, Jeff describes himself as a "generalist" that "know[s] more than a little bit about every aspect" and believes his contribution to projects is his "ability to take it through every phase of the project and then understand the schedule and budget implications and to be able to be decisive." Ultimately, the OPM provides the owner with peace of mind as they navigate the project though any issues that arise. Jeff is capable of this by drawing from his extensive construction background. His career began at Boston Medical Center as an Assistant Director of Design and Construction from 1995 to 2012 [15]. This experience working for a hospital meant Jeff understood the complexities of multiple buildings sharing utilities lines and the unique requirements of laboratories. Jeff then joined KVAssociates Inc as a Project Manager in 2012 and became a Project Executive in 2016 [15]. This 28-year career allows him to provide tremendous expertise at every level and makes him an asset at every project site.

### 2.2.2 Designer - Stantec

Stantec was the design firm on the Kaven Hall renovation project. Rooted in a storied past of excellence, Stantec works on a variety of technical projects around the world. Originally founded in in 1954 in Edmonton, Canada, D.R. Stanley Associates began as a one-person environmental engineering firm. Throughout the 1960s, the company grew to 50 employees and began pursuing water systems and infrastructure projects internationally. Urban land development was added in 1976 as the company made its first acquisition. In the late 1980's, rapid expansion brought specializations such as structural engineering and interior design to the company. In 1998, all assets and associated firms within the company were unified under the Stantec name. In 2006, Stantec began its expansion into the New England region and now operates six offices in the State of Massachusetts. In Stantec merged with ADD Inc to position itself in the region [16]. ADD-Stantec had previously worked with WPI on concepts involving Kaven Hall.

Working as an architectural and interior designer, they focused on making Kaven a modern and usable space as well as serving as the main point of contact for design-oriented decisions. The Stantec team is displayed below in Figure 3. Specializing in architectural design, they selected subconsultants to advise and make decisions in areas such as fire safety and HVAC. Stantec has extensive experience working on projects with institutional settings ranging from K-12 schools to higher education [17]. This particular project team, while experienced, has mostly worked on traditional classroom and university hall projects.

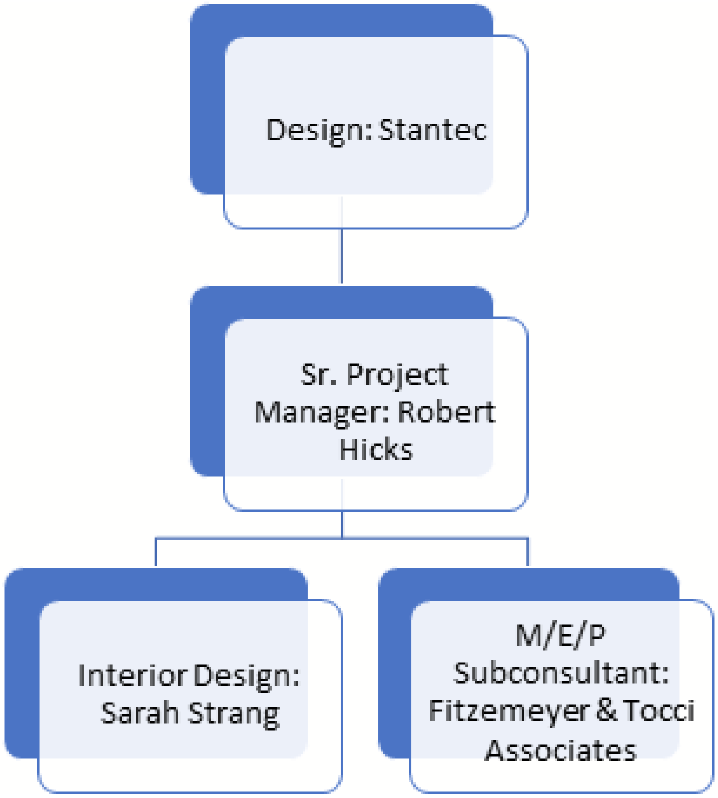


*Figure 3 Design Team OBS (Organizational Breakdown Structure)*

#### 2.2.2.1 Architect – Bob Hicks

Robert (Bob) Hicks was part of the design team from Stantec as he used his extensive architectural expertise to assist the Kaven Renovation Project. He received a BA from Amherst College in 1973 and an MA in architecture from the University of Pennsylvania in 1977[18] . After graduating, Bob worked as a Project Manager for SOM Boston and the Architects Collaborative from 1980 to 1985 and 1985 to 1988, respectively[19]. After, he worked as the Director of Project Services for Hoskins Scott and Partner from 1988 to 2001, and then as the Senior Project Manager for SMMA from 2001 to 2017 [18]. Bob then worked as the Principal at JCJ Architecture from 2017 to 2019, until he landed at Stantec as a Senior Project Manager in 2019 [18]. He gets involved in projects early on to identify opportunities by pursuing and wining work and remains involved throughout the design, documentation, and construction phases [20].https://usc-wordedit.officeapps.live.com/we/wordeditorframe.aspx?new=1&ui=en%2DUS&rs=en%2DUS&wdenableroaming=1&mscc=1&wdodb=1&hid=08B120A0-30BE-C000-D589-6113C79DFFF9&wopisrc=https%3A%2F%2Fwpi0-my.sharepoint.com%2Fpersonal%2Fjyip_wpi_edu%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F1be30cada1a840f9a4bc8aab2ed6461f&wdorigin=DocLib&wdhostclicktime=1644853177259&jsapi=1&jsapiver=v1&newsession=1&corrid=e35e9e6d-a1ca-4614-bc71-dad04454c82f&usid=e35e9e6d-a1ca-4614-bc71-dad04454c82f&sftc=1&mtf=1&sfp=1&wdredirectionreason=Unified_SingleFlush&rct=Medium&ctp=LeastProtected - _ftn5 Bob's specialty is higher education clients and was involved in many high profile projects with Harvard, Massachusetts Institute of Technology, Wellesley, University of Massachusetts, Framingham State University, Worcester Polytechnic Institute, and Providence College [21]. This extensive background with higher education clients allows Bob to address the intricate needs a school poses and the complex systems required for laboratories throughout every phase of the project.

##### 2.2.2.2 Interior Designer – Sarah Strang

Sarah Strang was the interior designer for Stantec on this project. Working together with architect Robert Hicks, they provided the interior and functional design input to the Kaven Hall Renovation Project. Sarah has been employed by Stantec as an Interior Designer since 2016. Prior to that, she was an instructor for an "Advanced level Interior Architecture" studio course at Boston Architectural College. She received her Bachelor of Arts from Lafayette College and Master of Interior Architecture from Boston Architectural College. Her experience in interior design contributes greatly to the project.

#### 2.2.3 Consigli

Founded in 1905 as a masonry company, Consigli evolved over the past 100 years to become on the largest full-service Construction Management (CM) firm in the Northeast and Mid-Atlantic [22]. Today, Consigli offers a wide range of services from Project Management (PM), lean project delivery, Mechanical/Electrical/Plumbing (MEP) services, pre-construction services, scheduling, and many more management and construction services. This growth was no coincidence and is directly attributed to the company values of a passion for building, developing a culture of accountability, and a focus on turning customers into “Raving Fans” [23]. Their passion for building means Consigli welcomes “complex projects that challenge… creativity and call for innovation,” while a culture of accountability ensures a “Do what we say we will do” attitude [24]. While most would be satisfied with a contractor that upholds these two values, Consigli takes it a step further by dedicating themselves to the customer. Their aim is not to complete a job and leave a client satisfied. Instead, they want to provide such great services that the client becomes an enthusiastic admirer of the company. Consigli achieves this by working closely with clients to understand their unique problems, challenging their own assumptions, and drawing knowledge from in-house craftsmen that address key constructability issues.

The Consigli Construction Company was perfect for the Kaven Hall renovation due to their extensive renovation portfolio. They expanded their construction portfolio to include renovation projects in 1998 with the restoration of UMASS Amherst’s Old Chapel [24]. Since then, the company performed countless renovations and historic preservations. Some of the most notable are: First Church in Cambridge, MA; Old South Church in Boston, MA; State of New York Office of General Services in Albany, NY; Trinity Church in Boston, MA [25]. These complex projects over the years allowed Consigli to refine the skills required to address the unique problems faced in all renovations, and those present in the Kaven Hall project.

### 2.2.4 Project Manager

The project manager at every construction site must lead the project team to guarantee a quality project within time and budget. A difficult task to consistently replicate since each project is unique and will have its own set of problems along the way. Despite what the project team encounters see Figure 4, the project manager must adapt and use the tools available to minimize impacts and produce the quality product promised to the owner.

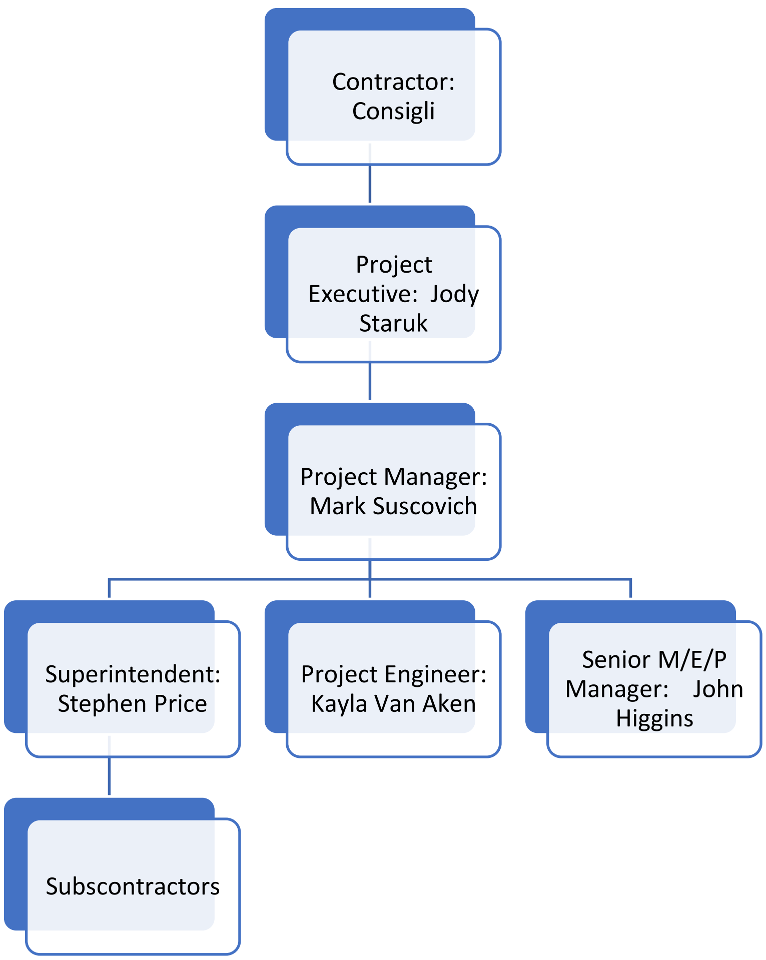


*Figure 4 Construction Team OBS (Organizational Breakdown Structure)*

These results are achieved with the five basic functions of a project manager: planning, organizing, staffing, directing, and controlling the project [9]. The plan must focus on the work to be performed and must include project objectives, performance requirements, and clear milestones. The planning step includes contingencies to offset unforeseen problems, and the preparation of formal change order agreements when there are changes to the scope. The project manager must organize the project around the work to be accomplished. This includes developing work breakdown structures that divide the project into specific measurable units of work, and project organization charts that defines individual responsibilities. Staffing is considered one of the most important aspects of project management, since the wrong team can undermine the best efforts of project managers. While selecting staff, the project manager must clearly define the work to be performed, explain what is expected of each team, and how their work fits into the overall project. The project manager must lead and provide direction for the project. This includes serving as an effective leader by coordinating all important tasks and ensuring teams have the resources required to complete their work. The final function of a project manager is to control the project site. This is achieved by monitoring project performance, maintaining a current milestone chart, and overseeing the monthly cost chart. These activities allow the project manager to maintain a record of planned work vs. accomplished work and planned expenditures vs. actual expenditures. This allows the project manager to keep track of schedule and costs to prevent any disruptions. The final and most important aspect of project management is keeping everyone informed to prevent unexpected surprises and keeps all parties up to date. This allows for quick response times, minimizes possible impacts on schedule and time, and provides the owner with confidence. These five basic functions of a project manager are the principal tools used during the construction process to provide a quality product on time and within budget.

The Kaven Hall renovation project provided some unique circumstances that required the PM to perform some abnormal duties. The Covid-19 pandemic required the PM to enforce additional safety protocols and difficulties in the procurement of materials that were met with unique solutions. Being a renovation, several pre-existing conditions were encountered. This caused the PM to lead the construction team in resolving newly discovered problems that often increased the scope. All these changes were primarily addressed with the contingency built into the Guaranteed Maximum Price contract. Therefore, the PM was consistently reviewing and reworking the Hold/Contingency/Allowance log to make sure adequate funds were available to complete the work.

#### 2.2.4.1 Mark Suscovich - Project Manager

The Project Manager for the Consigli Construction Management firm that WPI hired to deliver the Kaven Hall Renovation project was Mark Suscovich. After earning his degree from Northeastern University in 2011, Mark worked as a civil engineer for the Boston based engineering firm, Bryant Associates, for 5 years and became a licensed professional engineer in 2015 [26]. In 2016, he joined the Consigli team as a project manager [26].

Mark performed all of the duties listed in the previous Project Manager section at the WPI Kaven Hall Renovation project site. The subcontractor selection process was done through an open bidding process that allowed several contractors to submit a bid for specific work items defined by Consigli. During the subcontractor selection process, Consigli factored in financial stability, safety, current workload, and previous work quality [27] . This allowed Consigli to confidently select subcontractors that can complete high-quality work. To ensure quality work during the rapidly changing pandemic environment, Mark and the Consigli team went above and beyond with keeping everyone informed. Several contractor meetings defined the uphill battle they faced and promoted inter-company cooperation. To guarantee the information passed onto the subcontractors was the most up to date, Consigli held weekly Owner/Architect/Contractor (OAC) meetings with

WPI and the design team, Stantec. This constant communication promoted a team-like atmosphere as everyone worked together to resolve the problems encountered at every turn.

### 2.2.5 Project Executive – Jody Staruk

The Project Executive for the Consigli Construction Management firm that WPI hired to deliver the Kaven Hall Renovation project was Jody Staruk. She earned a bachelor's and master's degree in Civil Engineering from WPI in 2002 and 2003, respectively[28]. Jody began her career with Consigli as a project engineer and worked her way up from project engineer (2003), project manager (2006), senior project manager (2016), and then project executive (2017) [28]. Consigli defines the project executive responsibilities as someone who, "will provide overall direction and supervision of projects including oversight of project managers, engineers, and administrators, establish operation priorities, maintain satisfactory relationships with owners, OPM's, subcontractors, consultants, establish and execute plans for financial success"[29]. Jody assumed overall accountability for the Kaven Renovation site while assisting in the development of standard operating procedures, lead business development, and proposals [29]. In short, she oversees the project at the highest level while promoting Consigli's business interests.

### 2.2.6 Project Superintendent - Stephen Price

Stephen Price was the Superintendent for Consigli on the Kaven Hall Renovation Project. He began his career in construction by joining the Carpenters' Union at age 18. Specializing in the craft of drywall and metal framing, he advanced through the ranks to become area foreman, lead foreman, and eventually superintendent of projects.

He began the transition from a career in the building trades to construction management about 12 years ago as a field superintendent for Fusco Corporation of New Haven Connecticut. His self-described "high energy level", motivation, and desire for work led him to quickly advance in both his careers in the trades and in management. With Fusco he worked on projects of various scope and cost, ranging from $10 to $160 million, which allowed him to develop his project management skills. After 11 and a half years with Fusco, Stephen started a new position with Consigli and was put to work on the New Academic Building Project at WPI in June 2021. Within three days, he was promptly assigned as Superintendent on the Kaven Hall Project.

As defined by Consigli, a Superintendent "provides overall administrative and technical support management at designated construction sites" and is a role that "requires thorough knowledge of company policies, procedures, project goals, plans, specifications, and contract requirements." Onsite, the Superintendent was responsible for aspects such as safety, quality control, schedule, and communication between parties. Working together with the Project Manager, they make up the leadership aspect of the contractor's project team.

## 2.3 Interviews

As part of research on this MQP, interviews of WPI faculty and project personnel were conducted. Interviews are an important tool in understanding roles, obligations, and otherwise unknown information on a project. They are an effective means of gaining detail and personal experiences pertaining to the project. Faculty and key WPI (owner) stakeholders were interviewed as a means of understanding the wants, needs, and satisfaction of the end users. Project personnel were interviewed in order to gain more insight to the intricacies of the project, its daily operation, and challenges. Together, the information gleaned from these accounts help form a better-informed image of the project and where the process could have been improved.

### 2.3.1 Faculty

To better understand factors of the renovation such as the needs of WPI and the Civil, Environmental, & Architectural Engineering Department, members of the faculty were interviewed. The following faculty were interviewed: Professor Carrick Eggleston – Department Head, Wenwen Yao – Environmental Lab Manager, Russ Lang – Civil Lab Manager, and various professors. To establish a background on the WPI perspective of the project and the key goals of the renovation, Department Head, Professor Carrick Eggleston was interviewed. Questions regarding the faculty perspective as well as the design process were included. Both lab managers Russ Lang and Wenwen Yao were interviewed. Their operation and maintenance duties, and technological relevance are key to both the undergraduate and graduate population of WPI. The labs serve as an invaluable teaching tool to the department. Professors and Teaching Assistants make up the majority of the occupants of Kaven Hall. They are the ones utilizing the building on a day-to-day basis. As a large amount have occupied the building before and after the renovation, their input to the changes provides input to project quality and satisfaction.

### 2.3.2 Project Team

Different members of the Kaven Hall Renovation Project team were interviewed to gain a better understanding of their involvement on the project. The key parties involved in a project are the owners, architect/designer, and contractor (OAC). Each brought different assets and viewpoints to the project.

Functioning as the designers on this project, Stantec and their subconsultants created the design based off of input from the owners and constructability comments from the contractor. Acting as both experts of design as well as active listeners and decision makers, they played a key role in the outcome of the renovation. Stantec's experience, decisiveness, and communication between their subconsultants and other project stakeholders are aspects that can be more effectively learned through interviews.

### 2.3.3 Owner

The owner party for this project was WPI, and their interview identified the methods in determining the operational criteria of the project. WPI was primarily represented by Nick Palumbo, WPI Director of Design and Construction, and Jeff Lussier, the Owner's Project Manager form KVAssociates Inc. These two ran the weekly OAC meeting that oversaw the progress and mitigated problems promptly as they arose. Their interviews shed light on the initial scope defining process and its evolution to address newly discovered issues. They provided high level information on creative success stories, and the opportunity costs that come with decision making. Their leadership addressed Covid guidelines to protect the trades, and ensured the project continued its course despite all surprises.

### 2.3.4 Contractor

The Consigli team was interviewed to provide insight on the specific intricacies of the project, its daily operation, and challenges from the contractor's point of view. Both the Project Manager, Mark Suscovich and Site Superintendent, Steve Price, were asked a series of questions that focused on a broad range of topics. These topics included the Consigli methodology for building a good project team during the subcontractor selection process. How problems were identified and mitigated along the way, and the schedule impacts of an evolving scope. The process of addressing WPI requests like an early turnover. The interview also focused on the tools used to manage the project, its changes, and keep all parties informed in a timely manner. This interview provided an insightful view into the creative and often adaptive roles the contractor must take during a renovation.

## 2.4 Procore

Like many other construction firms, Consigli used the construction industry's leading construction management software, Procore, to keep everyone on the same page. This software allowed contractors to manage every phase of the project on one platform, from pre-development and bidding to project completion [30]. This was all possible on ProCore because the software provides "one source of truth" for all parties involved [31]. This was done by centralizing all project documents on one platform and streamlining communication by closing the communication loop [32]. It connected the owners, design team, general contractors, and sub-contractors in one location. It guaranteed all parties have access to the most immediate changes and the mobile collaboration tools let this information reach everyone in the field [33].

The software maintained and logged all aspects of the project. This included daily logs, progress reports, drawings, RFI's, schedules, specifications, submittals, timecards and much more [30]. It is highly customizable and allowed individuals to see the schedule in various ways from Gantt charts to day, week, and monthly calendar views [34]. This allowed all collaborators to know which days they are needed on the jobsite, their specifically assigned tasks for the workday, and relay photo documentation and descriptive information back to the management team [34]. Providing the construction management team with eyes and ears throughout the project allowed them to make real-time decisions that may affect the cost and schedule. The software also allowed the owner and management teams to oversee all costs including payment applications, payment status, budgets, real-time labor cost, progress billing and invoicing [32]. The main ProCore features are displayed below in Figure 5.

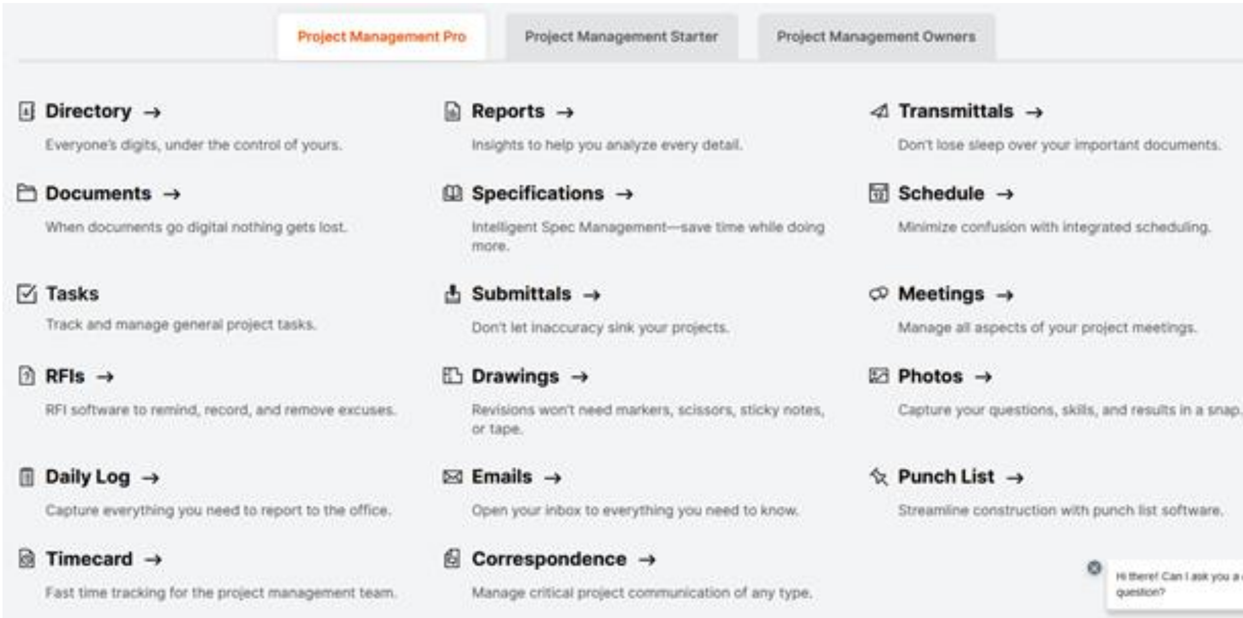


*Figure 5: [ProCore Project Management Tools] [33]*

All these features provided contractors with tremendous assistance in a difficult field. A study of general contractors revealed that 83% agreed that ProCore helps identify areas of improvement on their projects, and 86% agree that ProCore increases visibility in the health of their projects [33]. This high customer satisfaction shows the software is working as intended and provides to real world results and savings. On a typical project, general contractors say they saved 11 days on average by using this software. Making Procore an extremely helpful tool in an industry that must constantly control both cost and schedule to satisfy the client's rush to market.

With these benefits, it's no surprise the Consigli Construction Company uses ProCore for "pretty much everything." They also use Timberline for their cost management system, but that is primarily for "internal budgetary, to communicate with… accounting." But it all circles back to ProCore, and all documents get "uploaded to ProCore to get documented there." The reason for this due to the centralization of all documents and that are open to all parties. It makes it easy to "download the entire project onto a flash hard drive and hand it over… submittals, RFI's, drawings, the entire closeout package… all the financials will be on there." The software ultimately helps Consigli organize and manage every aspect of the while keeping all parties involved.

## 2.5 Pandemic Impacts

The global COVID-19 pandemic has impacted the way human activities throughout the world are carried out. This particular project was no exception and served as a case study of several pandemic impacts.

### 2.5.1 The Early Pandemic

On March 16, 2020, Boston became the first city in the country to halt all "nonessential" construction work amid COVID concerns [35]. Originally meant to last 2 weeks, this ban would last well into May 2020. The Massachusetts Building Trades Council (MBTC) unanimously voted in favor of calling for a statewide suspension of construction from April 3 – 30, 2020 [36]. A survey conducted by the Associated General Contractors of America (AGC) in May of 2020 indicated that 66% of respondents in the Northeast had halted projects that were underway in April 2020 [37].

In addition to these developments WPI, like many other institutional clients, announced a temporary freeze on all "non-essential" capital projects on April 29, 2020 [38]. This decision effectively halted both the mobilization of the Kaven Hall and the groundbreaking for the proposed residence hall at the current site of the WPI Townhouses. The original project timeline for the Kaven Hall Renovation called for a start date in April 2020, but would not resume until after the Pandemic shutdown. Full mobilization and work on the project began in May 2021.

The stoppage of work was far from the only impact that the pandemic had on the construction industry. As a result of project postponements and cancellations, the nationwide construction workforce plummeted by 975,000 jobs in April 2020 [39]. A similar ripple was felt across the Architect, Engineer, and Contractor (AEC) industry. In addition to the job losses in construction, 85,200 Architectural and Engineering jobs were lost in the same time span.

While many projects were wound down and secured, the projects deemed "essential" continued under a new level of scrutiny. They would be pioneering the safety protocols required to continue construction and more importantly protect the workforce within the relatively unknown constraints and hazards of the pandemic. Safety protocols such as requiring daily temperature readings and symptom tracking surveys before entering the site, mandatory mask wearing, social distancing, and increased sanitization were implemented [40]. Previously, the demand for personal protective equipment (PPE) such as N95 respirators by the healthcare industry led many Boston area building trades unions to collect and donate any stock they could find [41]. Projects continuing or resuming work were now faced with a PPE supply shortage of their own, leading to a potential limit on what activities could be performed on projects.

#### 2.5.2 Lasting Effects

One of the lasting effects of the pandemic is the disruption of the global supply chain. Virtually every industry has felt the repercussions of this. An AGC survey conducted in May 2020 indicated that 54% of suppliers had notified contractors that deliveries would either be delayed or cancelled [42]. In March 2021, another AGC survey reported that 52% of respondents were facing a shortage of construction materials, equipment or parts and that 32% had faced a shortage of craftworkers [43]. As a result of material shortages, an increase in lead times and prices impacted the producers, suppliers, and customers. As of September 2021, 89% of contractors responded stating they had difficulty finding craft workers [44]. These challenges faced across the construction industry have affected the schedule and cost of projects nationally.

## 2.6 Contract Structure

The most frequently used contract type is the competitively bid contract. This is because almost all publicly funded project uses a competitively bid process to ensure a competitive price and prevent taxpayer money from being wasted [45]. The selection process begins with the owner issuing a notice to bidders with a complete set of plans and specifications detailing the project within the bid package. Various contractors will review these documents and submit a bid detailing the estimated cost to complete the project. Once all bids are submitted the owner will review the lowest bids and select the lowest responsible bidder. The main factors in selecting a responsible contractor are [45]:

1. Technical competence and experience
2. Current financial position based on the firm’s balance sheet and income statement
3. Bounding capacity
4. Current amount of work under way
5. Past history of claims litigation
6. Defaults on previous contracts

This process is straightforward and carries several positives and negatives. The main advantage is that it guarantees the lowest possible price for construction and all bidders are treated fairly. The disadvantage is that all plans and specifications must be complete prior to the notice for bidders, resulting in a longer project lifetime. Change orders can be difficult to negotiate and can become quite costly since the owner is now in a contractual relationship with the contractor. A contractor can identify poorly defined plans, bid low, win the contract, and negotiate high prices for change orders. This will put the owner in a tough position as he weighs the opportunity costs of each change order. There are two main types of competitively bid contracts, lump-sum or stipulated sum and unit-price contracts.

In a lump-sum or stipulated sum contract, the contractor quotes a price for all the work and services detailed in the notice to bidders. This includes profit, direct costs (labor and materials), and indirect costs like field supervision, equipment maintenance, etc. [45] This provides the owner with the exact cost for total specified work but makes any change orders difficult. The owner makes monthly payments to the contractor based on the estimated percentage of the total job completed. This is an estimate that needs to be only accurate enough to determine the percent complete of the total project. Therefore, there isn’t a need for large field teams to quantify the exact amount of work completed. The principal disadvantage is the lack of flexibility in this contract in regard to change orders. It can lead to an adversarial relationship between the contractor and owner and are a major source of cost overruns [45]. To protect the owner, a rate schedule for labor and equipment for extra work should be agreed upon before signing the contract [46].

Unit-Price contracts provide a flexible alternative to lump/stipulated sum contracts with a competitive bid. Unit-price contracts are used because the quantity of work cannot be determined with enough accuracy to for a contractor to use a lump/stipulated sum contract [9]. The project is therefore broken down into work items that are measured in units like cubic yards, linear and square feet, and piece numbers [45]. The contractor quotes prices for units based on guide quantity specified. Most contracts allow for renegotiation in case the field quantity deviation exceeds or underruns by 10% [45]. Progress payments are based on precisely measured field quantities, so a major disadvantage is that the owner does not know the final price until project completion.[9] Meanwhile a major disadvantage to the contractor is that pay is distributed after unit work completion so the revenue curve lags behind the expenditure curve [45]. To offset this the contractor may need finance the difference or unbalance the bid by inflating prices for early items and reduce prices for later items [45]. The main advantage is the flexibility to varying field quantities reducing the need for change orders.

### 2.6.1 Negotiated Contracts

The second most widely used contract type is a negotiated contract. Within this type, the owner enters into a contract with the contractor and negotiates the price and method of reimbursement. This allows the owner to select the contractor on a criteria other than the lowest bid and can include experience, reputation, fee structure, etc [45]. This means favoritism can play a major role in the selection process, making this contract structure not suitable for public works projects. The project documents and specifications to be totally or partially complete by the selection process, which allows for phased construction.

### 2.6.2 Cost Plus Contracts

The cost plus fee is the most common fee structure for negotiated contracts. The contractor is reimbursed for the expenses incurred that are detailed in the contract and typically include all direct expenses for labor equipment, and materials along with overhead charges to manage the project [45]. The contractor also receives a fee that is the profit or markup. The main items for negotiation are the amount of fee, charge schedule used in reimbursement, award and control of subcontractors, and charges for equipment [45]. The main four types of fee structures are Cost + percent of cost, + fixed fee, + fixed fee + profit-sharing clause, + sliding fee. The cost + percent provides the contractor with a percentage of the cost for profit. It can be subject to abuse since there is little incentive to be efficient or economical. The cost + fixed fee provides the contractor fixed profit that does not change. This incentivizes the contractor to get the job done quickly but may also result in the use of expensive reimbursable materials and equipment. Cost + fixed fee +

profit sharing rewards the contractor that keeps costs low by sharing the difference between the final cost and the estimated cost. Cost + sliding fee is similar to cost + fixed fee + profit sharing, but it penalizes the contractor that exceeds the budget [45].

### 2.6.3 Design Build contracts

In a design build contracts the owner deals with a single firm that provides both design and construction services. It is very common in complex industrial construction projects with short completion windows. The main advantage is that all differences or disputes between the design and construction teams are handled quickly and internally [45]. This prevents the potential for adversarial relationships since prolonged problem resolution can result in profit losses. The enhanced coordination between designer and constructor improves communication and efficiency, which ultimately allows for phased or fast track construction. This means the design and construction occur concurrently, and the field work can begin before the design is complete.

### 2.6.4 Design Bid Build

The design bid build project deliver method is known as the traditional sequence of construction. The owner selects a design team to develop the project plans that are presented to construction firms for competitive bidding. The contractor is selected based on the lowest construction cost. This requires project plans to be final before the selection process and eliminating the opportunity for phased construction.

### 2.6.5 Construction Management at Risk Contracts

The construction management at risk (CMaR or CM@R) project delivery method has the construction manager coordinates the project but also assumes the responsibility during the construction phase [45]. It is similar in Design Bid Build and requires separate contracts for the design team and contractor, but is not selected on the basis of the lowest total cost and can be fast tracked [45]. The CM at risk is similar to a general contractor and awards all subcontractor, place vendor purchase orders in their name, and coordinate all activities to complete the project. Therefore, they face the same risks and uncertainties as a general contractor like cost overruns, subcontractor bankruptcies, product failure, cost of rework, etc [46]. A CM at risk can select a lump sum, cost reimbursement or more commonly a guaranteed maximum price (GMP) [9]. With a GMP, if the CM at risk is required to cover all costs that exceed the GMP unless the scope of the project is clearly adjusted. If the price is less than the GMP, then the owner may keep the saving or share it with the CM firm. A GMP most importantly set aside for allowances and contingencies, money reserved for known-unknowns and unknown-unknowns, respectively. The reserved money for problems that arose throughout the lifetime of the project eliminated the negotiation of change orders and sped up problem response times. This contract style is attractive to organizations that periodically build complex structures but do not want to maintain a full-time construction staff in house, and projects expecting many unknowns.

# 3.0 Methodology

` The goal of this project is to develop a set of guidelines identifying best practices for historic renovations to mitigate potential scope creep and cost overruns while delivering a project on time and within budget that exceeds client satisfaction. This was achieved through the following steps.

1. Learning about and accompanying the professional team in weekly OAC meetings and site walks to document the process and conduct interviews to fill information gaps and define the original scope.
2. Research, collect, and review project documents to identify changes to the original scope, timeline, and cost.
3. Identifying consistently reoccurring problems and items that negatively impacted the cost and schedule.
4. Select the most problematic items common in renovating existing structures for an in-depth analysis.
5. Review the methods of resolution used by the professional team to mitigate these common problems and conduct a literature review to identify other possible solutions.
6. Develop a set of construction management recommendations to assist professional teams in anticipating and resolving common renovation problems that may impact the cost and schedule.

## 3.1 Project Familiarization

While observing the Kaven Hall renovation as a student from afar, it was difficult to conceptualize all the work items and project teams that collaborated to mitigate problems that arose along the way and maintain the cost and schedule. To get a firsthand view and meet the professional teams responsible for the renovation, the student team attended weekly Owner/Architect/Contractor (OAC) meetings. Careful attention was paid, and extensive notes were taken to understand the dynamics of the meeting and learn about the changing topics at hand, arising problems, and document their resolution. The weekly meeting minutes packet provided an in-depth summary of the past week, and the plan for the coming work weeks. After the OAC meetings, the student team joined the professional teams on their occasional site walks where the project staff assessed the general project status, reviewed OAC meeting specific items, and provided on-site solutions. These opportunities were used to take notes, progress photos, ask questions, and visualize the concepts brought up in the meeting. The OAC meetings and site walks helped the student team learn about problems that arose during the construction phase, understand daily operations, and identify the main contributors.

After this initial introduction, the student team set out to learn more about the individual professional teams and fill information gaps. Descriptions were created of the owner, architect, and contractor to understand the contractual role of each party and short biographies were developed of individual team members. These biographies identified their project specific roles and highlighted their educational background, job history, and specialties. This knowledge allowed the student team to understand their day-to-day responsibilities and identified topics each role provided additional information on. Specific questions were developed for each professional project team to fill in project information gaps. Interviews were conducted with the owner, architects, and contractor teams. Several WPI faculty members were interviewed to collect additional user and planning participation information. The current Civil, Environmental, and Architectural (CEAE) Department Head, Carrick Eggleston was interviewed to understand their role in scope planning, level of involvement, and overall satisfaction. Discussions were held with members of the faculty to gauge the needs and satisfaction of the department. The Environmental Lab Manager, Wenwen Yao, was interviewed to understand her role in scope planning, finding alternative lab spaces, early turnover, and the state of the lab upon project delivery. All these interviews helped the MQP team understand the role each individual contributed throughout the project, filled information gaps, and recreated the scope development process to identify the original scope.

## 3.2Project Documentation Research

The next step of the project was to develop a document fact-finding strategy to research work other projects groups and professionals conducted previously and collect internal project documents and communications. Previous WPI MQP's that focused on Kaven Hall were identified and researched for proposed scope, cost, and duration.  Types of contract structure and Covid-19 pandemic impacts were researched. For internal project documents and communications, the project team collected Consigli project documents within their ProCore database, internal WPI communications, and all other WPI documents relating to the Kaven Hall Renovation. This section identified the methods used to research, collect, and review these project documents and communications.

The first step was to reach out to individual parties and request access to sensitive project documents. Consigli was contacted and the team requested access to their project specific ProCore portfolio. All MQP members signed a Non-Disclosure Agreement with WPI Facilities to agree that sensitive project information requested for review was not to be released. The MQP group requested to be included on WPI facilities and the CEAE Department email chains.

During the wait for the documents and communication requested, the project team conducted background research on previous MQPs, contract structure, and general pandemic impacts to better understand the specific aspects of this project. The project team began with reviewing all previously conducted WPI student Kaven Hall MQPs accessible on the WPI Library MQP database. This was done to learn about the history of Kaven Hall, its current conditions, and what other project teams chose to focus on. During the review of these projects, the proposed scope, problems identified, recommendations, and the cost/schedule to complete was noted. After learning more about the structure, several textbooks were reviewed for information on different contract structure types. This was to learn about contracts as a construction management tool and determine why the CM at risk with a GMP was the best contract for the Kaven Hall Renovation Project. The most common contract types, project delivery methods, and fee structures were reviewed to identify their individual pros and cons that make a contract best suited for the type of work to be completed. Finally, the team researched the general Covid-19 pandemic impacts affecting the construction industry through a literature review of articles to understand the general difficulties the construction industry was facing. This information was collected to help the project team identify the root causes of schedule and cost impacts during the construction. It would help to identify whether specific problems faced through the project lifetime where outside the control of the project team, and how they mitigated these industry wide challenges.

As the background research was conducted, the project team incrementally received the requested project documents and internal WPI communications. Consigli provided read only access to their Kaven Hall ProCore Project Portfolio. To better understand and navigate the program, each project team member completed the ProCore Certification for Students course. This tutorial taught the various ways the program can be used and identified all accessible project documents. The team began collecting downloadable documents like the original schedule, contracts, specifications, Request for Information (RFI's), submittals, etc. This record of Consigli project data identified the remaining documents needed to complete the picture, and the project team contacted the WPI Director of Design and Construction, Nick Palumbo, for the remaining documents. The project team requested access to financial documents like pay requisitions, the change request log, and the hold/contingency/allowance log to better understand the impacts to cost and schedule. Additional information on rework items and work items remaining after project delivery was requested. Some of this information was also achieved through internal WPI faculty communications request. The project team collected and reviewed communications regarding problems teachers were having in connection with the project. This provided a picture of customer satisfaction and identified individual remaining problems.

## 3.3 Identification of Problematic Items

After documenting and collecting the items in the previous objectives, the project team identified consistently reoccurring problems and items that negatively impacted the cost and schedule. The OAC meeting minute packets were the first documents reviewed. These packets provided project updates, and they highlight the high-level items discussed, problems to be solved, and provide other project teams with reminders like outstanding submittals and open RFI's. After reviewing these packets, a list was created of reoccurring problems and singular problems that greatly affected the scope, cost, or schedule. The OAC meeting notes from and site walk notes were reviewed next. These notes were a record of the conversation that occurred during the meetings and site walks that may not have necessarily been included in the meeting minutes. They provided in-depth accounts of the problems that arose, solutions presented, team discussions, and the solutions selected. We used these notes to provide greater details on the items identified in the OAC meeting packets and add new problematic items to the list.

The project documents were used next to identify previously missed items and determine the true impact of the problematic items identified. The final project Gannt schedule was first reviewed to identify all items that were defined as added scope, unforeseen impact, and increased scope. The Gannt schedule was then viewed in Oracle Primavera P6 (a scheduling software) for a more in-depth analysis that allowed the project team to compare the original duration times to the actual duration and identify the items with the greatest impacts. This also allowed the project team to determine how one work item impacted the subsequent items. The items identified within this analysis were added to the list from the OAC meetings. This list of problematic items allowed the project team to search for and review specific RFI's and items within the WPI financial logs to understand the problems in greater detail and determine its financial impact. The WPI financial logs were also used to identify change orders and contingency items that increased the original project scope. These items were identified in the recreated Gannt schedule and a detailed analysis of their impact on the schedule was conducted. The final list, Kaven Hall Problematic Items, contained extensive details on the problems that arose, their solution, and their impacts to both cost and schedule.

### 3.4 Select Problematic Items

Once the analysis of the Kaven Renovation Project concluded, the project team began identifying and selecting the most problematic items common in renovating existing structures for an in-depth analysis. This research was conducted to identify if the problems encountered during the Kaven Renovation were foreseeable, and to determine whether the professional teams could have taken preventative measures earlier on. To determine this, our project team conducted an extensive literature review on many case studies that focused on renovating existing structures. During this process, we developed an ongoing list of common renovation problems, their solutions, and their impacts on the cost and schedule. The list of common renovation problems was compared to the problems encountered on the Kaven Hall project. This allowed the project team to determine if the Kaven Hall project problems were common in all renovation or specific to Kaven Hall.

### 3.5 Analyze Project Problem Solving Methods

The fifth step of the project required an analysis of problem-solving methods utilized by project professionals on the Kaven Hall project and beyond. There are three means that were followed to achieve this. In the first method, a thorough review of project materials was undertaken. Notes taken during weekly OAC meetings were analyzed for any mention of sticking points and resolved issues. The written distributed OAC meeting minutes documents were also compared. The schedules and minutes were compared for any carried over items and issues as well as changes that may have rooted from a problem. Components of interest include project roadblocks, safety updates, schedule impacts, and logs of holds, contingencies, and allowances. OAC meetings were attended by all members of the MQP group and a debrief was conducted after each. The group created meeting minutes and notes from the student group's discussions with the project advisor were also consulted for mentions of observed problem solving. Problematic items previously identified as part of objective 4 were analyzed for the effectiveness of the applicable resolution methods. Details such as the type of problem, size, cost, duration, and resolution method were analyzed. The list of items was cross referenced with the OAC minutes/notes as well as the group's own internal notes. Further information was gathered through the conducted interviews. Interviews with project personnel allowed the opportunity to seek on project issues and learn about what had happened prior to the MQP group joining the project. These were the most direct means of evaluating project problem-solving.

A literature review of renovation case studies and publications was carried out to glean lessons from a broader reach than just this project. Sources such as industry publications and journals as well as magazine/online articles were also consulted. Detailed case notes were compiled for scope, budget, schedule, contract structure, unforeseen conditions, and project setting. While not every source may not have included such information, a wide range of sources made up for this.

A large amount of renovation projects undertaken did not always have published articles about them. An alternative means of research was seeking out projects from websites of contractors and designers. Such featured project profiles may have necessary information such as a cost range and challenges overcome. Some of the project profiles may contain enough information, while others may not. A way of addressing this was to reach out to the parties behind the project and ask for additional information. Reaching out to individuals who work with historic projects as part of those companies could also be an additional resource to pursue.

## 3.6 Develop Construction Management Recommendations

The sixth and final step in this project involved the development of a set of construction management guidelines to assist professional teams faced with common challenges that may occur in renovation projects. A key component of this objective was understanding what obstacles to anticipate and how to resolve them so that impacts to cost and schedule are minimized. Important impacts to client satisfaction could include levels of communication, safety record, and the number of items that require rework.

The severity of problems and their potential impacts to cost and schedule plays a role in their importance. The feasibility and likelihood of the problem's occurrence is also a matter to consider. Priority is placed on commonplace problems that have the ability to stop/delay a project or increase its scope and cost. Some potential problems of less likelihood may take extensive resources to avoid and may not be as worthwhile to invest resources into avoiding The cost and schedule impact of problems as well as the techniques to avoid them must be weighed carefully. Some issues are simply unavoidable and have occurred on a project despite the team's best efforts. All challenges noted from the Kaven Hall renovation project and other case studies were considered and proper recommendations developed.

# 4.0 Project Management Review

A project management review process was applied to the Kaven Hall Renovation Project. Techniques including Engineering Economics, the review of project changes, and the review of payment requisitions were carried out. The use of BIM and other forms of construction technology such as information management systems, project scheduling software on the project was analyzed and critiqued. The results from the project management review combined with lessons from the literature review shaped the recommendations section.

## 4.1 Literature Review

A literature review was conducted to learn about the problems encountered in other renovation projects, conclude the most common problems in renovations, and the identify recommendations made by other project teams for future projects. While dozens of case studies were reviewed, only a few were relevant to this MQP project and included the three objectives outlined in the introduction sentence. This section briefly presents the goal of each case study, building type, problems encountered, their recommendations, and an analysis of whether these recommendations are applicable to the Kaven Hall renovation.

The first case study was Challenges in Renovation of Vintage Buildings by Ibrahim Erdem and David B Peraza. This case study focused on a flawed structural renovation project, discussed the common challenges engineers face during the renovation, and presented several recommendations [47]. The building was a six story vintage residential building with exterior load-bearing brig masonry walls, wood floor framing, interior cast iron and wood columns [47]. The main problems encountered during the construction was the assumption by the engineer that the 4th floor column was cast iron instead of wood, several incorrect calculations, dimensional errors, and failure to communicate between the engineering and design teams. Although these problems where not encountered in the Kaven Hall renovation, some of the recommendations presented were applicable to the Kaven Hall project and contributed to the discussions during the development of the recommendations within this project.

This case study presented six different recommendations. The first was that continuity of a project team throughout the project lifetime is important [47]. The staff that prepared the design was not the same team that prepared the predesign and were not aware that the predesign team determined that the girders could not support the additional weight of the fireplace. Relaying information to maintain project knowledge during staff turnover is crucial to eliminating errors. The Kaven Hall renovation did not experience this problem because of steps taken by the project management team to relay information and project knowledge to the five different superintendents during the project lifetime.

The second recommendation was to ensure the compatibility of the project and construction firm [47]. This case study project was relatively small for the contractor, and therefore did not receive the proper attention it deserved. This did not apply to the Kaven Hall project as Consigli provided more attention than usual to this renovation project by conducting weekly OAC meetings.

The third recommendation was quality checking the work of junior staff that caused the incorrect calculations [47]. This also did not apply to the Kaven Hall renovation as the experienced project management team did not miss any major mistakes by junior staff.

The fourth recommendation was that experienced staff be involved in in field inspections when unexpected conditions are discovered [47]. This recommendation was used by the Consigli team in several instances like when discovering the unpredictability of the terracotta interior walls.

Once discovered, the project management team adjusted the demolition process to maintain safety complete the job.

The final recommendation was to ensure project staff are familiar with uncommon materials or systems[47]. Luckily in the case of Kaven Hall no uncommon materials were discovered. Therefore, this recommendation did not apply.

The second case study reviewed was Front End Planning for Renovation Projects by George Gibson. This case study focused on identifying the critical success factors in front end planning, a critical process used to uncover pre-existing conditions when defining the scope and a structured approach during the project execution [48]. There was no specific building evaluated in this case study. Instead, a survey was distributed requesting information on how organizations conduct front end planning differently for renovations projects [48]. This case study also did not include specific problems but focused on developing eight different recommendations for future projects.

The first was to develop and consistently follow a defined front end planning process [48]. The Kaven Hall project did have a front-end planning process that included the use of GPR and LIDAR scans that greatly assisted the project. However, this MQP report believes it could have been used more extensively and a more detailed analysis is presented below in the BIM/TECH section.

The second recommendation was to ensure adequate scope definition prior to the construction phase [48]. This recommendation was would have greatly assisted the Kaven Hall renovation as several major items were added to the original scope during the construction phase including but not limited to: water quality lab fume hoods, exterior green door, eyewash stations, tempered water loop, office ceiling and lights. These items were not identified for replacement at the beginning of the project and were difficult to incorporate within the original schedule.

The third recommendation was to thoroughly define existing conditions [48]. This is another recommendation that would have greatly assisted the Kaven Hall project. Several pre-existing conditions were not discovered until the construction phase including the unstable terracotta walls, I beam encased in concrete, and green tiles that are prone to chipping. Identifying these issues earlier could have saved some time during the demolition process.

The fourth recommendation was to select the proper contracting strategy early [48]. This primarily focuses on the contract structure, which was specifically selected to address the expected unforeseen conditions and is further discussed below in the contracts section.

The fifth recommendation was to align the project team, including key stakeholders [48]. Although the Kaven Hall project did include the participation of faculty and staff, they could have been more integrally involved. Especially in the case of the early basement and water quality lab turnover. The functionality of the lab was extremely limited upon turnover and the CEAE faculty became aware of the limitations only after turnover. This complicated the use of the alternative lab spaces around campus as other lab managers expected CEAE student to free up space for other students.

The sixth recommendation was to staff critical project scoping and design areas with capable and experienced personnel [48]. This recommendation used during the Kaven Hall planning process as the design team incorporated CEAE faculty opinions early in the project.

The seventh recommendation was to address labor force skill and availability early in the planning process [48]. This was addressed very early due to the pandemic impacts. The OAC parties anticipated labor difficulties and did a tremendous job guaranteeing the subcontractors were available to complete the work. The most difficult subconsultant to get ahold of was Fitzemeyer & Tocci Associates that were responsible for the MEP systems. Although they were difficult to get ahold of at times due to Pandemic Impacts, they were able to complete their work.

The final recommendation was to provide leadership at all levels for the front-end planning process. This recommendation did not apply to the Kaven Hall project as the OAC guidance provided great leadership throughout the project.

The third case study reviewed was Identifying Barriers to Address During the Delivery of Sustainable Building Renovation Projects by Corey Cattano. The goal of this reading was to identify barriers to address in the delivery of renovation projects using a literature review and a case study [49]. This reading presented many barriers common in renovations and presented the solutions to these barriers from a literature review and the case study the reading reviewed. The solutions from the case study are very specific to the renovation project studied within the reading while the solutions from their literature review were more broad and more generally applicable to other projects. Therefore, this MQP project reviewed only the most relevant barrier and solutions.

The first barrier was that pre-existing conditions are identified late in the design process. [49]. This is a frequent problem in most renovation. This barrier was the third recommendation of the Front-End Planning for Renovation case study and the first of the following case study. As previously discussed, it was very common in the Kaven Hall renovation. This case study recommends that the design and construction team meet early to identifying project constraints and accelerate the discovery of pre-existing and unforeseen conditions [49].

The second barrier was that renovations often do not account for interactions between systems [49]. This occurred in the Kaven Hall as the OAC team did not take into account the different steam traps. Fuller Hall had a 100 lb steam trap but Kaven Hal had a 20 lb steam trap.

This discrepancy was not identified until the work was already underway. Fortunately, it did not impact the construction process. However, this is a simple barrier to resolve and could have been addressed during the design phase, and failure to identify these inter-building can create a much larger problem later in the project. The case study recommends a whole-systems thinking approach to account for the inter-connected buildings [49].

The third and final barrier was the limitations of downstream systems that were not accounted for in upstream decisions [49]. This occurred with the fire panel and annunciator. The decision to install the annunciator was the result of a Worcester Fire Department request late in the construction phase. Although the annunciator was ordered, it was not compatible with the current fire panel and some wiring rework was required to get it to function with the current wiring system. The new panel was also significantly larger, and it had to be relocated to the ADA entrance lobby. The case study recommends selecting the project team early and accelerating the iterative design process with a team based process [49].

The final case study was Renovation Projects: Design Process Problems and Improvement Mechanisms by Panagiotis Mitropoulos and Gregory A. Howell. This case study, "investigates the problems that occurred during the design process, analyzes the cause of design iterations and rework, and proposes changes that can improve the design process [50]." This case study focused on the renovation of a 10-floor office building and presented several recommendations common in other case studies.

The first recommendation was to accelerate the discovery of existing conditions [50]. Identifying pre-existing conditions early in the design process is a common theme for renovation projects and was previously discussed in several other case studies.

The second recommendation was to identify key constraints like physical conditions, other design and construction constraints [50]. This is slightly different but similar to pre-existing conditions and identifying interactions between building systems. These constrains will dictate the downstream systems so identifying them early will provide more time to rework any downstream issues.

The third recommendation is to select the project team early [50]. This is another common and previously mentioned recommendation that will help the project team collaboratively evaluate the design and confirm it meets all project constraints.

While these case studies were vastly different in nature, the main source of all their problems and the principal focus of their recommendations were pre-existing and unforeseen conditions. The reason pre-existing and unforeseen conditions is the biggest factor in renovations is because another project team built the current structure long ago using the materials and building techniques of that era. The age of the building also has an immense impact on the current conditions as the structure will settle over time and will be significantly more prone to deterioration. Therefore, a modern construction team will never truly know the current conditions of a structure at the start of a project. This is the reason why most of the recommendations centered around the need to thoroughly investigate the building to comprehend the current conditions, adapt to the findings, and keep all professional teams well informed.

#### 4.1.1 Pre-existing/Unforeseen conditions

Pre-existing and unforeseen conditions were so common in the literature review and the Kaven Hall renovation that they were categorized as unidentified items that required replacement, unforeseen difficulties discovered along the way, and unidentified pre-existing conditions.

The unidentified items that required replacement were due to a failure by the owner to properly identify all items to be replaced within the original scope. This is a major issue in renovations that severely impact the cost and schedule as it requires the project management team to incorporate the added items into a completed schedule. This type of unforeseen occurred several times within the Kaven Hall renovation. The largest item was the water quality lab fume hoods that were severely deteriorated and constructed of the wrong materials for the current lab chemical uses. This was a difficult fix due to the basement location of the lab and the exhaust vents running to the attic. Identifying this late in the project could have severely complicated several downstream systems and required significant rework since it would be a major demolition process and a difficult installation in semi-completed project. Luckily, it was identified early in the construction phase and caused minimal changes to the schedule. The cost was accounted for within the contingency and allowance budget of the GMP. Another major item for identified for replacement was the eye wash and tempered water loop. The additional eye wash station was not within the original project scope, but the addition of one more required them all to conform to the current code. The realization late in the project schedule made it significantly more difficult to incorporate into the schedule and complicated the project further.

The unforeseen difficulties discovered along the way were items that were overlooked by the design team or required more time to resolve during the construction phase. An example of this in the Kaven Hall renovation was the terracotta tiles that were prone to collapse. This presented a safety issue that required additional precautions to prevent injuries and caused a design change. Instead of just creating a door opening, the terracotta tile were demolished to the ceiling due to instability. Another example is the stream trap differences between Fuller Hall (100 lbs) and Kaven Hall (20 lbs). This was a design failure that did not take into account the difference at the start, and the problem was addressed during the construction phase. The office heater pipe locations being approximately one foot away from the walls were another discovery that complicated the project cost and schedule. The space between the heater and wall was unacceptable so box shelves were placed in between.

Unidentified pre-existing conditions were the classis pre-existing conditions that were simply unknown to all parties. For the Kaven Hall renovation, the I beam encased in concrete was the perfect example. There was no real reason to expect this, making its discovery almost impossible. This category of unforeseen conditions is the most difficult to anticipate and can cause the greatest problems. Discovering a major unidentified pre-existing condition can change the perceived understanding of the building, meaning it may not be structurally sound. This can create a need to return to the design phase to re-analyze the entire construction as was the case in the Challenges in Renovation of Vintage Buildings case study above.

## 4.2 Contracts

While any contract described in the Contracts Background section could have been used, the best contract style for the Kaven Hall Renovation Project needed to address the unique factors present within the project. The most important factor being that this was a renovation project, and all renovation projects encounter unforeseen conditions that call for change orders and increased costs. Although WPI prioritized quality, no owner wants to enter an agreement without knowing the final cost. Being a school, WPI did not have the in-house construction capability to dedicate to the project and required additional expertise to complete a project during a global pandemic, making OAC cooperation vital to a successful project delivery. These project specific factors were unique to the Kaven Hall Renovation and required a contract structure that best addressed each factor.

The contract and project delivery method proposed by Consigli that WPI entered for the Kaven Hall Renovation Project was Construction Manager at Risk with a Guaranteed Maximum Price (CM at Risk with GMP). As described in the Contracts Background section, this is a negotiated contract where the CM is a single source of management that coordinates all activities required to complete the project without exceeding the GMP. Being a negotiated contract, WPI prioritized quality by selecting a construction firm based on experience, reputation, and prior relationship instead of cost. This provided WPI with more control in their decision-making process and guaranteed greater confidence in their expected outcome. This confidence was increased with the CM at Risk project delivery method for a few reasons. WPI received the professional expertise they did not have in house from a CM firm that assumed risk and was liable for a successful project delivery. Meaning it was in the best interest of both parties to complete the project on time and within budget. The final and most important aspect of this contract style was the GMP which addressed several of the unique Kaven Hall factors. First and foremost, the GMP set a cost limit to the construction unless change orders are negotiated with additional cost. This comforted the owner by establishing a price ceiling for the total project that included money set aside for allowances and contingencies, money reserved for known-unknowns and unknown-unknowns, respectively. The reserved money for problems that arose throughout the lifetime of the project eliminated the negotiation of change orders and sped up problem response times. It promoted OAC cooperation as the teams came together to resolve most issues, and the owner can review the costs. Allowing the owner to review the financial documents ensured honesty, eliminated potential owner- contractor rivalries, and promoted a collaborative approach to problem resolution. This quick collaborative OAC party approach was vital to keeping the project moving forward by reducing time lost while waiting for a response. For these reasons, CM at Risk with GMP was the best contract style to address the unique factors posed by the Kaven Hall Renovation and ensured a successful project completion.

While the CM at Risk with GMP contract between contractor and owner has many benefits, the relationship between contractor and subcontractor provides additional financial benefits. The contracts between Consigli and their subcontractors were done through a semi-open bidding process. During this process Consigli sent out drawings and scope sheets to pre-qualified subcontractors. Consigli then reviewed the bids and selected the lowest bid subcontractors for WPI approval. This system provided Consigli and WPI with significant cost savings. Although the CM at Risk with a GMP contract is a negotiated contract that does not incorporate the same cost saving approach as competitively bid contracts, the subcontractor selection process was an open bid system that provided the lowest cost to complete the project.

Before accepting CM at Risk with a GMP as the best option, a review of the cons of this contract style was necessary. First and foremost, unless there is a profit-sharing clause within the contract that provides the contractor with an incentive to deliver the project below the GMP, the contractor is likely to run up costs to meet the GMP. Since this contract anticipates changes, the budget for allowances and contingencies are typically greater than other contracts. Therefore, the owner may end up paying more with a GMP than another contract type [51]. The GMP also puts the contractor at risk since they are required to cover any additional costs over the GMP. Therefore, a contractor that anticipates exceeding the GMP may cut corners and provide inferior work to save money. The success of a CM at Risk contract relies on the performance of the construction manager and provides a single point of failure[52]. If the contractor is inexperienced, then the project will suffer tremendously. All these negatives associated with the CM at Risk with GMP come down to the owner-contractor relationship. A good relationship will disincentivize any foul play, while a bad relationship will guarantee these negatives.

Although the CM at Risk with GMP provides a significantly more positives than negatives, a review of the other major contract structures described within the Contracts Background section was required to ensure there was no other better option.

Since all competitively bid contracts select the lowest responsible bidder, the owner may not have a prior relationship with the selected contractor [45]. From an owner's standpoint, this is a major gamble, and an onboarding process is required for both the owner and the selected contractor as they establish a relationship. There is no guarantee the two parties will get along, and there are greater chances an adversarial relationship will develop that will complicate OAC inter-party cooperation. Conflicting parties' complicate projects and significantly increase the chances of schedule delays and cost overruns as infighting hinders an OAC team effort to problem solve. In the case of the Kaven Hall Renovation, the project schedule was severely complicated by the overlapping academic schedule, and severe schedule overruns would complicate that start of the academic year. Therefore, this gamble was not in the best interest of WPI. Instead, the owner preferred to select a construction team that WPI built confidence in through a long-standing relationship. These project specific requirements eliminated the chances of all competitively bid contracts including Design Bid Build.

Although Lump Sum and Unit Price contracts styles are typically used in competitively bid projects, they can also be used in negotiated contracts. The principal issue with Lump Sum contracts is that it requires a complete set of design plans before construction begins, and there is little flexibility for unforeseen conditions. Any changes to the scope require change orders, and the contractor will have an upper hand when renegotiating costs for changes. The Kaven Hall

Renovation design was not fully completed before the construction began, and like all projects change orders from unforeseen or pre-existing conditions were guaranteed. This also meant a final project cost was difficult to determine, eliminating the possibility of using a Lump Sum contract. A Unit Price contract carries the same final cost disadvantage since the total price isn't fully determined before construction begins because unforeseen conditions are expected to arise. Unit Price contracts are built to address the issue of unforeseen condition by quoting price by units like cubic yards. While this is perfect for excavation jobs, it becomes very difficult to measure project items in building construction by units. This also requires a team to conduct precise field measurements for pay, increasing costs and the number of people walking around a confined space. Due to the undefined final cost, difficulty in measuring work items as units, and the required additional project personal; a Unit Price contract was not an advantageous contract style for the Kaven Hall Renovation.

The final contract style reviewed was a Design Build. While this contract would provide the Kaven Renovation project with advantages in quick problem solving, it also requires a lot more involvement from the Owner. Having the same design and construction team completing the project means fewer check and balances within the process. Therefore, WPI would have to take on the inspection requirements that were assumed by the design team, Stantec, within the selected CM at Risk with a GMP contract. As previously noted, the Owner did not have the in-house construction capabilities for this project and preferred to outsource this work to a reliable CM agency and have the contractors work reviewed by an independent design team. For these reasons, a Design Build contract was not advantageous to WPI.

After reviewing the different contract types and determining how well each addressed the unique Kaven Hall project factors. It was clear that the CM at Risk with GMP was the best choice.

## 4.3 Organizational Breakdown Structure

The temporary elimination of the OBS hierarchy greatly contributed to team building but reinstating the OBS hierarchy to select a solution allowed the project to continue progressing forward. While the OAC Organization Breakdown Structure (OBS) displayed below in Figure 6 for the Kaven Hall Renovation project reflected a typical construction OBS, it typically appeared they were all on the same team. These interactions were primarily acknowledged during the weekly OAC meetings that included the WPI, Stantec, and Consigli teams. Consigli ran the meeting and presented the Owner and Design teams with the typical project updates on safety, schedule, MEP coordination, and document control that kept everyone current with project status. However, the typical OBS structural hierarchy instantly faded when a problem was encountered, and all team members entered open discussions on possible solutions. Everyone asked questions, presented ideas, and challenged them. When listening online though Microsoft teams, it became difficult to identify which OAC party a voice represented during this forum. The best idea was recognized and addressed by the OPM, Jeff Lussier, and a more detailed discussion followed, until the OPM stepped in, reinstated the hierarchy, and selected the course for action.

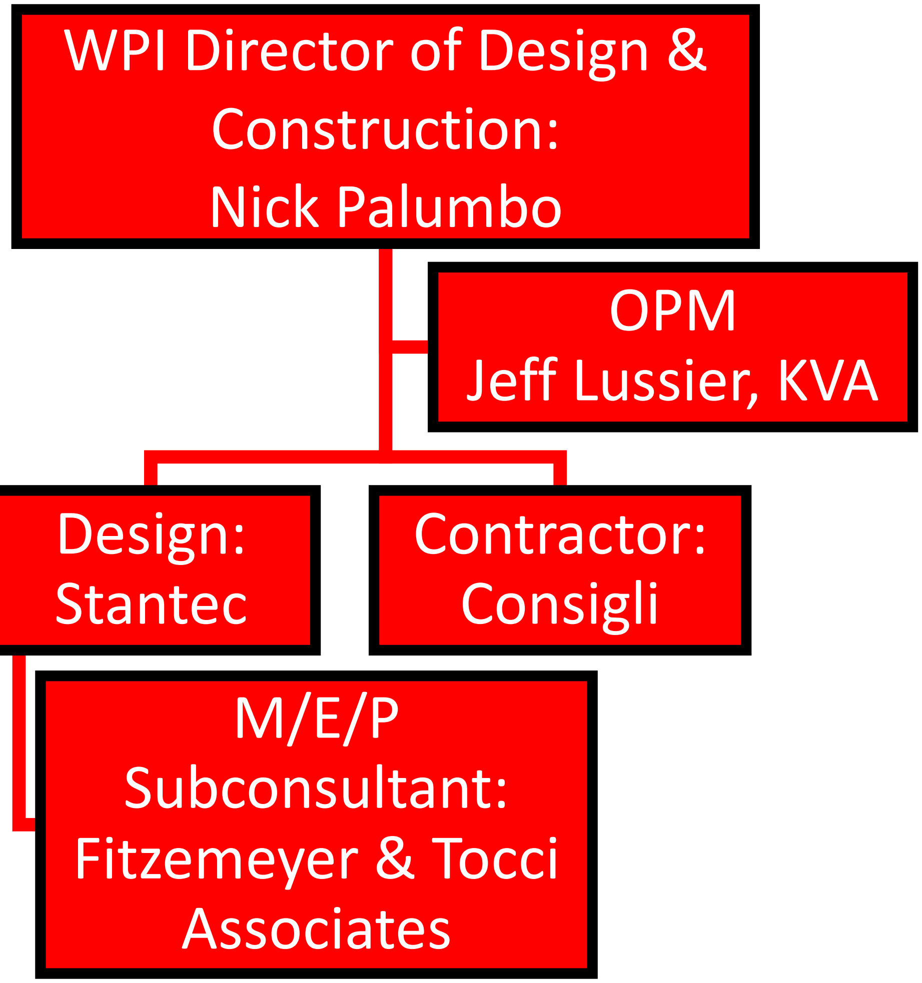


*Figure 6 OAC Organization Breakdown Structure*

Temporarily removing the typical OBS structural hierarchy constraints was the result of the OPM's, Jeff Lussier, management style. He intentionally tried to keep things light to make people feel comfortable and acknowledge all OAC members [53]. This his was achieved by establishing an open forum for problem discussion at the OAC meetings to get members to contribute and listening to all opinions. By making people feel heard, they felt recognized as an important part of the team and contributed further. The style was very successful during the Kaven Renovation Project as all OAC attendees offered ideas when needed. This method provided several positive results. The Owner team heard and considering a greater number of potential solutions.

Individuals felt recognized and individual professional team parties merged into an OAC team. This promoted communication, prevented adversarial relationships from developing, and reduced time spent on problem resolution. The temporary elimination of the OBS hierarchy greatly contributed to team building but reinstating the OBS hierarchy to select a solution allowed the project to continue progressing forward. All the OAC members know the right decision, but it takes someone to make a decision [53]. The indecisiveness of some teams are project killers that negatively impact the schedule, budget, and it slowly erodes individual motivation [53]. Therefore, it was necessary to reinstate the OBS hierarchy to make a decision,  keep everyone engaged and moving forward [53].

Throughout the Kaven Renovation Project, the construction crew OBS received a similar informal treatment at times to improve cooperation. The Consigli professional team OBS remained relatively constant, but the OBS between subcontractors was treated a little less formally. Typically, each subcontractor was responsible for and only focused on their clearly defined work items and often disregarded other subcontractors and their work. This outlook often created friction between subcontractor groups that can complicate a job and even result in cost and schedule impacts. While this is not extremely common, the friction does occur and is amplified by the some of the unique factors present in the Kaven Hall Renovation. Pre-existing conditions and pandemic impacts caused extensive schedule delays and constant adjustments, further amplify the chances of conflict between subcontractors. To prevent any complications from arising, Consigli conducted weekly subcontractor meetings, regular site walks with the foreman, and ran daily pre-operation meetings with the subcontractors [27]. During these times, the Site Superintendent, Stephen Price, and the PM, Mark Suscovich, coordinated with the subcontractors and detailed the problems encountered and their schedule impacts [27]. The mindset taken by the PM is, “let’s all get in a room figure out solutions and move forward [27].” This was a similar tactic used during the OAC meetings and essentially established a new inter-subcontractor team to address and resolve the problem at hand. The inter-subcontractor cooperation improved communication, prevented adversarial relationships, and reduced time spent on problem resolution. It was a vital tool used in the Kaven Hall Renovation to reduce frustrations and maintain motivation when dealing with a constantly changing schedule due to pandemic impacts and the regular discovery of unforeseen conditions.

## 4.4 MQP Review

From 2003 through 2018, five past MQPs have proposed varying levels of work to Kaven Hall and provided estimated costs. An Engineering Economics analysis was used to calculate the current value of the proposed renovation projects and compare them to the actual 2021-2022 renovation cost to gauge value.

### 4.4.1 Engineering Economics Analysis

The proposed project duration, scope, and cost data were extracted from past MQP reports. As the projects were researched, it became apparent that the estimated costs did not account for labor. The CLMA (Construction Market Analyzer) estimates that labor cost makes up 20% to 40% of the total construction budget [54]. To account for this, a 35% multiplier was applied to the estimated costs. The different MQPs, their proposed scope, costs, and duration are shown in Table 1

| **Proposed Cost, Scope, and Duration of Kaven Hall MQPs** | | | | |
|---|---|---|---|---|
| ***Year Proposed*** | ***Scope*** | ***Duration*** | ***Est Cost*** | ***Labor Adjustment (35%)*** |
| 2003 | Attic Renovation | 8.75 Months | $980,000 | $1,323,000 |
| 2009 | Attic Renovation | 7.5 Months | $1,820,000 | $2,457,000 |
| 2011 | Full Renovation | Not Provided | $1,760,000 | $2,376,000 |
| 2014 | Full Renovation + addition | 10.5 months | $8,500,000 | $11,475,000 |
| 2018 | Replacement (Steel Frame) | 10 months | $7,850,200 | $10,597,770 |
| 2018 | Replacement (Concrete Frame) | 10 months | $9,307,000 | $12,564,450 |

*Table 1 Proposed Cost, Scope, and Duration of Kaven Hall Renovation MQPs*

The scopes of the MQPs varied as did the estimated costs. The projects from 2003 and 2009 proposed renovations to the attic as well as the addition of code-required egress stairways and elevator. The 2011 and 2014 projects proposed a full renovation to the building with 2014 including an addition. The 2018 project included two framing options for a total replacement to Kaven Hall. The renovation durations estimated by the MQPs are close to the actual project duration. The original project duration was closer to the 8-month mark from the start of work in May 2021 to the intended issuance of the Certificate of Occupancy in December 2022. The duration difference can be attributed to the accelerated nature of the Kaven Hall renovation.

| Construction Cost Index Changes | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Year Proposed*** | ***Scope*** | ***Average Annual CCI*** | ***CCI AVG 2022*** | ***CCI % Change (i)*** | ***n (years)*** | ***Avg CCI Change*** | ***Avg Inflation Rate*** |
| 2003 | Attic Reno | 6694 | 12732 | 90% | 19 | 4.75% | 2.38% |
| 2009 | Attic Reno | 8570 | | 49% | 13 | 3.74% | 2.28% |
| 2011 | Full Reno | 9070 | | 40% | 11 | 3.67% | 2.26% |
| 2014 | Full Reno + addition | 9806 | | 30% | 8 | 3.73% | 2.46% |
| 2018 | Replacement (Steel Frame) | 11062 | | 15% | 4 | 3.78% | 3.43% |
| 2018 | Replacement (Concrete Frame) | 11062 | | 15% | 4 | 3.78% | 3.43% |

*Table 2 Years MQPs completed and corresponding Construction Cost Index Changes*

The estimated costs and their respective Construction Cost Indices were tabulated. The Construction Cost Index from 2022 was used to calculate a percent increase between the years. An average annual increase was calculated by dividing the total percent increase by the number of years between the year proposed and 2022. This was compared to the average inflation US rates provided by the World Bank. In all the above cases in Table 2, CCI increase outpaced the average annual inflation rates. With the change rates calculated and tabulated, the projected values could be calculated.

The concept of Future Value was used to convert the estimated project costs from the year proposed to the current (2022). The equation $FV = PV \times (1+i)^n$ was utilized. The initial cost estimates with the 35% adjustment for labor was used as the PV (Present Value) which was multiplied by 1 plus the annual interest rate ($i$) all raised to the power n (years). Table 3 shows the estimates calculated with CCI and Average US inflation.

| Future Values Calculated by CCI and Inflation | | | | | |
|---|---|---|---|---|---|
| ***Year Proposed*** | ***Scope*** | ***Est Cost*** | ***Labor Adjusted (35%)*** | ***Est Cost 2022 $FV=PV(1+i)^n$*** | ***Inflation Estimate*** |
| 2003 | Attic Reno | $980,000 | $1,323,000 | **$2,516,443** | **$2,068,460** |
| 2009 | Attic Reno | $1,820,000 | $2,457,000 | **$3,650,373** | **$3,293,704** |
| 2011 | Full Reno | $1,760,000 | $2,376,000 | **$3,335,432** | **$3,038,156** |
| 2014 | Full Reno + addition | $8,500,000 | $11,475,000 | **$14,899,570** | **$13,937,584** |
| 2018 | Replace (Steel) | $7,850,200 | $10,597,770 | **$12,198,144** | **$12,128,318** |
| 2018 | Replace (Concrete) | $9,307,000 | $12,564,450 | **$14,461,813** | **$14,379,030** |

*Table 3 Future (2022) Values of Kaven Hall MQP Costs*

With respect to scope, the adjusted values from past MQPs are low compared to the actual 2021-2022 renovation cost. The full renovation plus addition and replacement projects had the closest costs to the actual ($13 Million) when their scope was ignored. The 2011 renovation cost was considered an outlier and was considered for comparison to the actual project. The 2011 estimated cost fell between the two attic-only renovation costs from 2003 and 2009. This did not realistically track with the proposed project scope entailing a full renovation.

As a reality check, construction cost per square foot data by Cumming Insights was consulted. The construction cost for Academic/Classroom University Buildings on the East Coast was between $622 and $747 per square foot [55]. The average of $684.50 was multiplied by the square footage of Kaven Hall (41,400) as reported in WPI Facilities documentation. The resulting cost was $28,338,300 for a full replacement compared to the $12,198,143 - $14,461,813 estimated by the 2018 project. The 2018 project’s cost estimate included framing floor/roof construction, utilities, and foundation. This leaves out large amounts of costs such as those attributed to HVAC, drywall, plumbing, electrical, and furnishings. The MQP estimated project costs may also neglect aspects such as markup, contingencies, and change orders.

| **Kaven Hall MQP Estimates – Extrapolation for Full Renovation** | | | | | |
|---|---|---|---|---|---|
| ***Year Proposed*** | ***Est Cost*** | ***Labor Adjusted (35%)*** | ***Full Reno Est*** | ***Adjusted Cost 2022 FV=PV(1+i)*** | ***Inflation Est*** |
| 2003 | $980,000 | $1,323,000 | $5,292,000 | **$12,780,459** | **$8,273,842** |
| 2009 | $1,820,000 | $2,457,000 | $9,828,000 | **$15,840,406** | **$13,174,814** |
| 2014 | $8,500,000 | $11,475,000 | $9,782,328 | **$13,162,899** | **$11,881,658** |

*Table 4. Kaven Hall MQP estimates extrapolated for Full Renovation*

The remaining MQPs for consideration were further scrutinized and adjusted as shown in Table 4. As the attic was the most unfinished level of Kaven Hall pre-renovation, it was reasoned that it would be the most expensive floor to renovate and refit. Including the attic, Kaven Hall contains 4 levels (basement, first, second, attic). The estimated cost adjusted for labor was therefore multiplied by 4 to roughly estimate a renovation of every floor. The 2014 project with a full renovation and addition was also modified. The MQP report called for a roughly 7,600 square foot addition. The 2014 project group's estimated cost per square foot of $222.72 was multiplied by 7,600 SF to achieve a cost of $1,692672. That cost was subtracted from their original estimate. The remainder was labor adjusted and future values were calculated for both CCI and inflation. While the estimation methods may be considered rudimentary, the three estimates yielded values that bound the actual final 2022 project invoice value of $13.1 Million. The performance of the 2021-2022 renovation ranks well when compared to these estimates.

### 4.5 Pandemic Impacts

The COVID-19 Pandemic disrupted construction projects all around the world. The Kaven Hall Renovation Project was no exception. While the disruption was widespread, the severity of impacts varied as no two projects are exactly alike.

The effects could be seen throughout the life of the project. The Kaven Hall project fell victim to the onslaught of postponements and cancellations due to uncertainty during the early stages of the pandemic. Construction across the State of Massachusetts ground to a halt shortly after in mid-March 2020 and resumed later that spring with a renewed push on safety in an uncertain time [35]. Through the remobilization of the project in the spring of 2021 and to its completion in early 2022, there were additional impacts felt.

As mentioned in the background section, construction resumed with added precautions and safety measures. In adherence to both federal and local health guidelines, the Consigli team on the Kaven Hall project committed to a robust system of daily site temperature checks of site personnel, symptom surveys before entrance to the site, and the use of masks, extra ventilation, and social distancing. Throughout the site, signage with company COVID policies were prominently displayed. These measures followed on a largely indoor construction site proved important. These practices combined with the fact that the project began a year after the initial rapid pandemic expansion meant that instances of lost time due to project personnel contracting or spreading COVID were kept to a minimum as stated by Consigli personnel in an interview [27].

The lingering effects of the pandemic included shortages of both labor and materials. As the pandemic progressed, a strain on the global supply chain grew. Construction relies heavily on both materials and labor. Material cost reports reflect increases or decreases in unit cost of materials in a percentage. They are compared to the past month's prices as well as those from the past year. An important set of data for tracking construction material and labor costs is the 20-city average. Two labor cost indexes are also reported. The Skilled Labor Index tracks union wages and benefits of carpenters, bricklayers, and ironworkers. The Common Labor Index tracks union wages and benefits for laborers. The CLI can be seen in . The two labor cost indexes combine with the material price indexes to create the Construction Cost Indexes (CCIs) and Building Cost Indexes (BCIs) [56]. ENR (Engineering News-Record), a leading publisher of industry analytics and news, has compiled and reported both CCI and BCI since 1908 and 1915 respectively. These metrics can be used to track trends evaluate the overall "health" of the construction industry. The CCIs are calculated utilizing the sum of the 20-city cost average of 200 hours of common labor, 25 hundred weight (cwt) of standard structural steel shapes (pre-1996) or fabricated (post 1996), 1.128 tons of Portland cement, and 1,088 board ft of 2 x 4 lumber as seen in **Error! Reference source not found.** [57]. The BCIs are calculated utilizing the sum of 68.38 hours of skilled labor (bricklayers, carpenters, ironworkers) and the same quantities of materials as the CCI at a 20-city average cost and can be seen in Figure 8 [58].

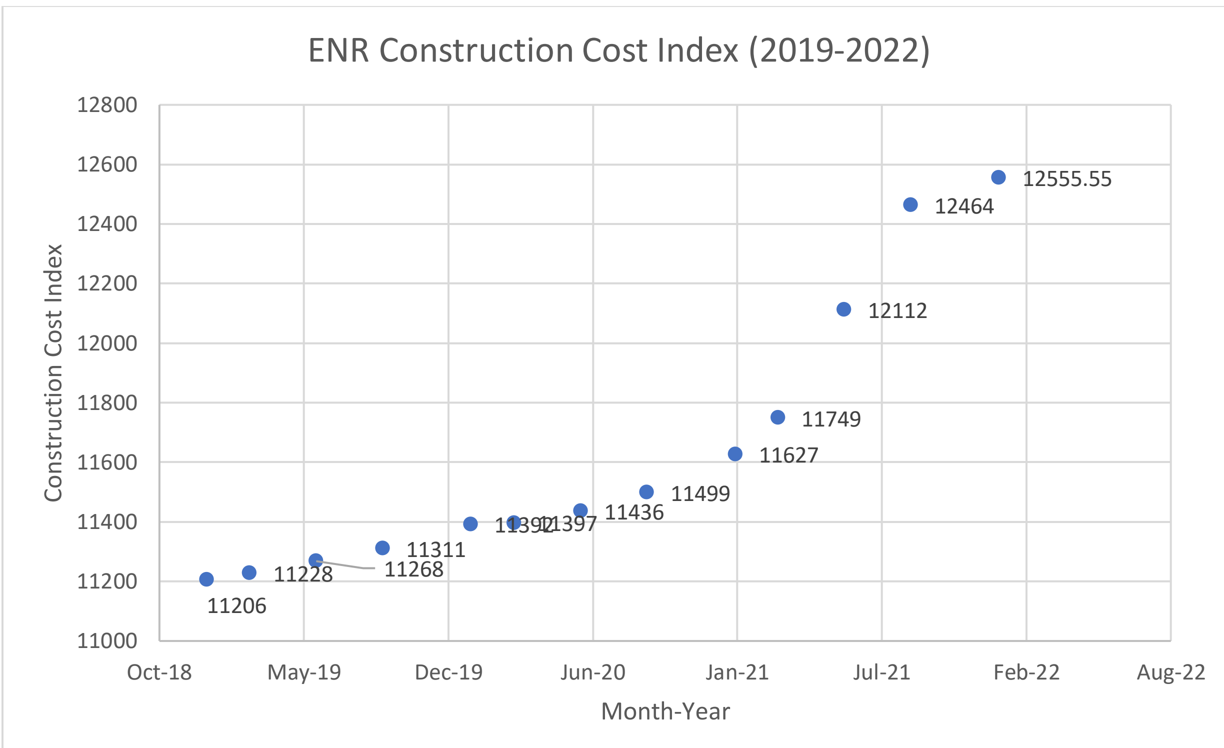


*Figure 7. Construction Cost Indexes from 2019 – 2022 in 3 month increments.*

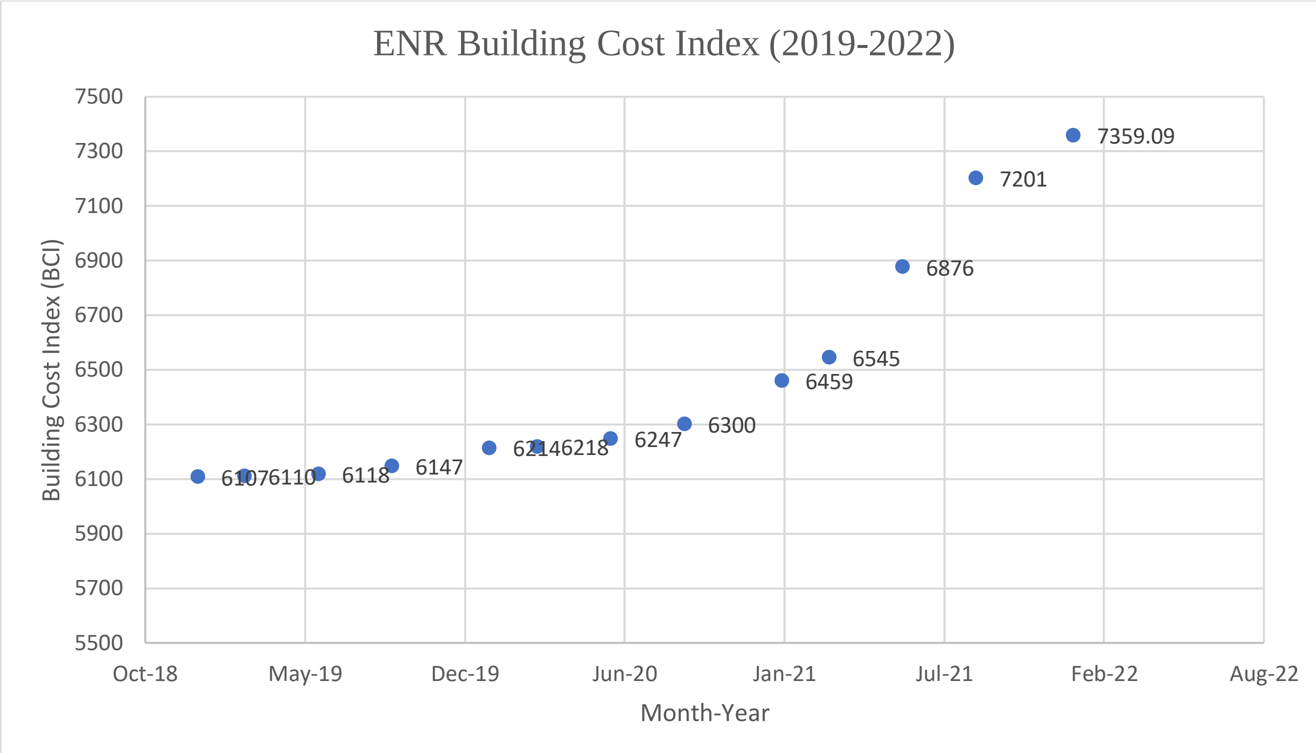


*Figure 8 Building Cost Indexes from 2019-2022 in 3 month increments*

Project cost and contractor profitability are intrinsically tied to the cost of materials and labor. An upset as large as the global pandemic had shifted typically predictable cost fluctuations to more dramatic increases. The initial restriction of activities as part of early efforts to curb the spread of COVID left factories and warehouses silent [59]. A temporary decrease in construction activity led to a decreased demand for material and labor. As restrictions came and went, construction restarted, and demand increased. What materials suppliers had, were quickly exhausted and restocks were far and few between. Prices on construction materials increased rapidly and contractors were faced with a labor shortage. Both common and skilled labor were accounted for as many trades were present on the project. Both indexes increased between 2019 and 2022, though the skilled labor index was more prone to fluctuation. In the end, the common labor index in Figure 9 and skilled labor index in Figure 10 increased a total of 4% and 6% respectively.

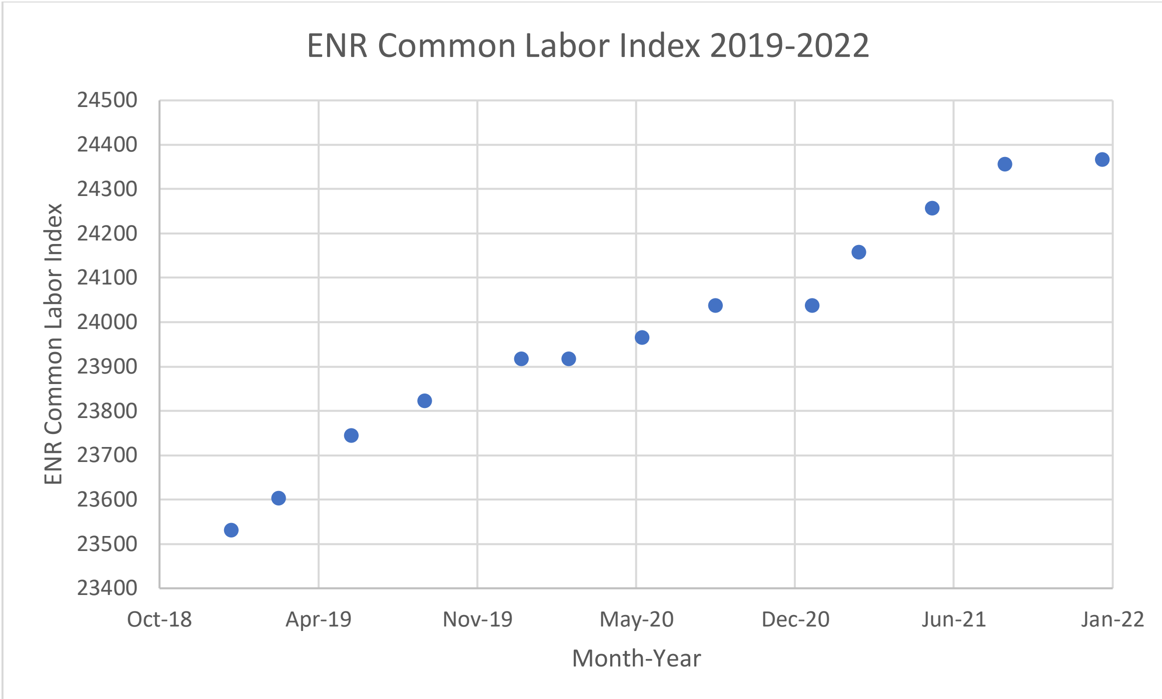


*Figure 9. Common Labor Index. January 2019 – 2022*

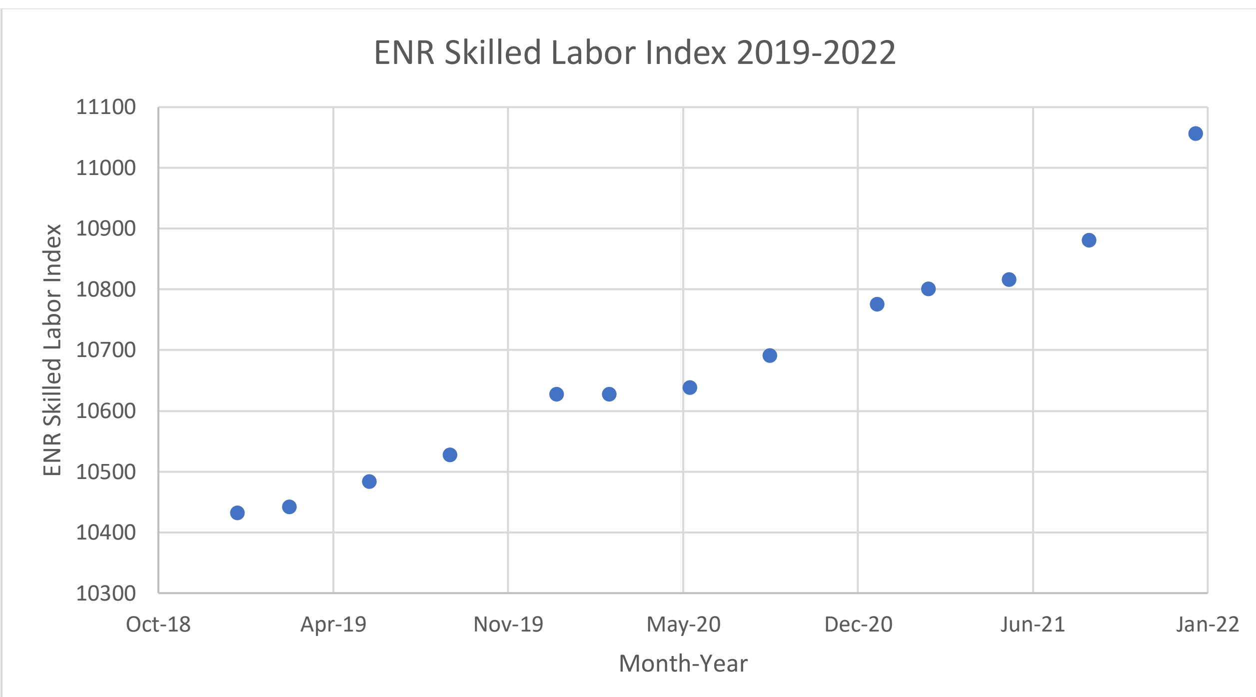


*Figure 10. Skilled Labor Index. January 2019-2022*

Data from a survey by the Associated General Contractors reported that 89% of contractors had difficulty finding craft workers [44]. Fortunately, Consigli had a presence of craft labor and management personnel next door at the New Academic Building (Unity Hall) Project which had continued in the time that Kaven Hall was postponed. In a way, the two projects enjoyed a synergistic relationship which helped lessen the impact of the labor shortage. Project Superintendent Steven Price was sent over from the New Academic Building project and quickly set to work on Kaven Hall in June 2021. Like many general contractors, Consigli did not self-perform all the work on the project. Both the design team and the contractor had faced issues with their consultants and subcontractors. As both parties were stretched between jobs and personnel, staffing and response times were somewhat of an issue. In the case of Stantec's sub-consultants, it was sometimes difficult to get site inspections and visits scheduled.

A key example of a pandemic related supply chain impact on this project was the Fire Annunciator Panel. Initially, it was planned to be installed in November of 2021. As of March 2022, the panel was still not installed. Multiple ship dates provided from the supplier elapsed with little to no updates. This was said to have been linked to the shortage of microchips that occurred as an effect of the COVID related supply chain issues [27]. This item pushed both the cost and schedule of this project. The annunciator panel was a crucial piece of life safety equipment required in order to pass an inspection that would grant a full C of O (Certificate of Occupancy). Without the new panel, the building remained functional utilizing its existing fire panel and suppression systems. However, this was only enough to allow for a TCO (Temporary Certificate of Occupancy), which cannot be kept indefinitely. Additional planning resources and labor had been allocated due to the lateness of the panel. The old fire suppression systems can only be dismantled following the commissioning of the new panel and its modern suppression system. This requires the remobilization of trades personnel from either Consigli or subcontractors which incurs additional working hours at a time far past project turnover. The new annunciator panel has been quoted to leave the factory by the end of April 2022. It was originally estimated to arrive in January. Until the annunciator panel could be installed and the fire suppression systems switched over, the building operated under a TCO.

More common materials used on the project such as structural steel elements, wood, and tile did not suffer as severe of shortages, however cost did increase. In figure 10, the Material Price Indices from 2019 to 2022 as reported by ENR In an extreme case, specialty materials such as the green veneer tiles used in hallways were made virtually unavailable. Due to the severe winter weather faced by Texas in 2021 and complications from COVID, the factory that produced the tiles could not fulfil any orders [60]. As new material could not be sourced, existing materials had to be salvaged from walls that were demolished. While this did rectify the supply issue, the margin for error was slim. Spare tiles were far and few between and the demolition work had to be completely methodically in order to deliver reusable tiles.

Increased costs and wait times for materials influenced the project and several decisions. The fluctuation in material prices meant that the final cost could end up far exceeding previous estimates. This occurred on the project with the gantry rail in the basement concrete labs. During the design process, an estimate for the required section of steel beam was received and approved by the owner. Between the design period in 2019 and when the material had to be ordered in 2021, the price of standard steel structural shapes rose dramatically from $53.86 to $73.42 per CWT [61] . In 2021 alone, the price had increased 31.5%. Due to this, the gantry rail item was removed from the project as a cost and time saving measure [27]. In the period that the project had resumed in 2021, the Material Price Index had increased 13.23% between March and June. It further increased 11.25% from June to September. The increase can be seen in Figure 11.

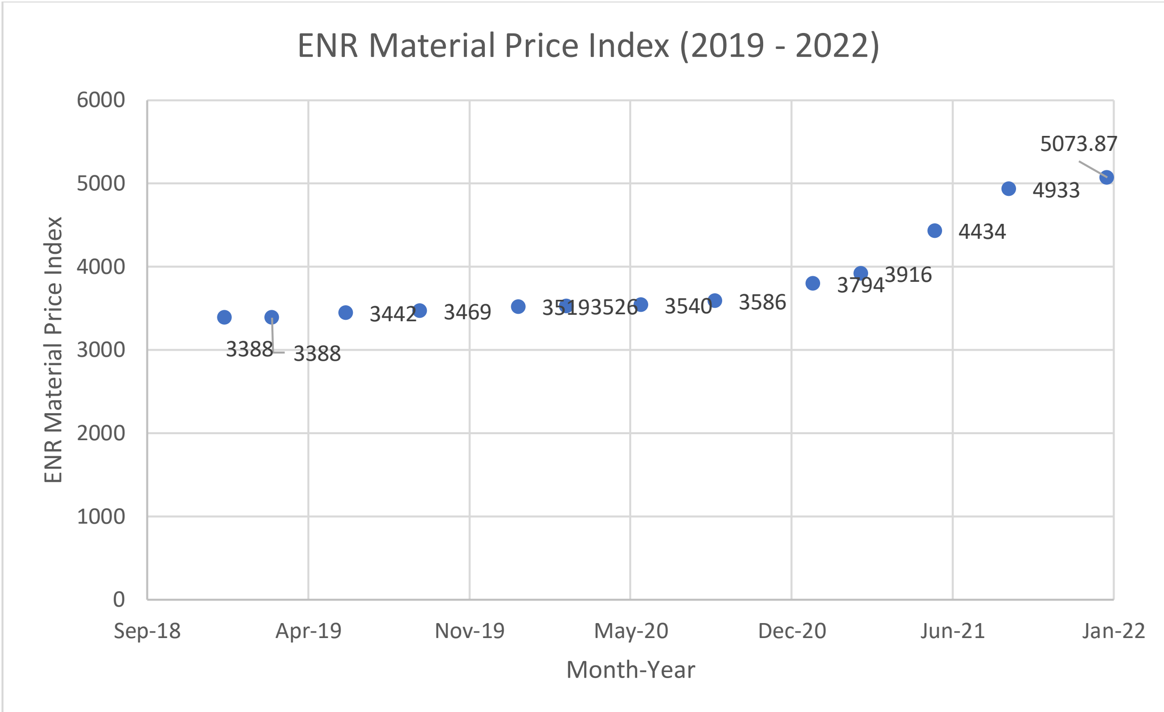


*Figure 11 Material Price Index from January 2019 to 2022 in 3-month Increments*

While some items on the project could be removed for cost reasons, there are others that could not. The occupancy sensors that were installed in classrooms and offices were an example. The number of sensors needed was calculated during the design phase, but when it came time to install there were supply issues. Due to increased lead-times from suppliers, decisions had to be made on which rooms would get certain types of sensors.

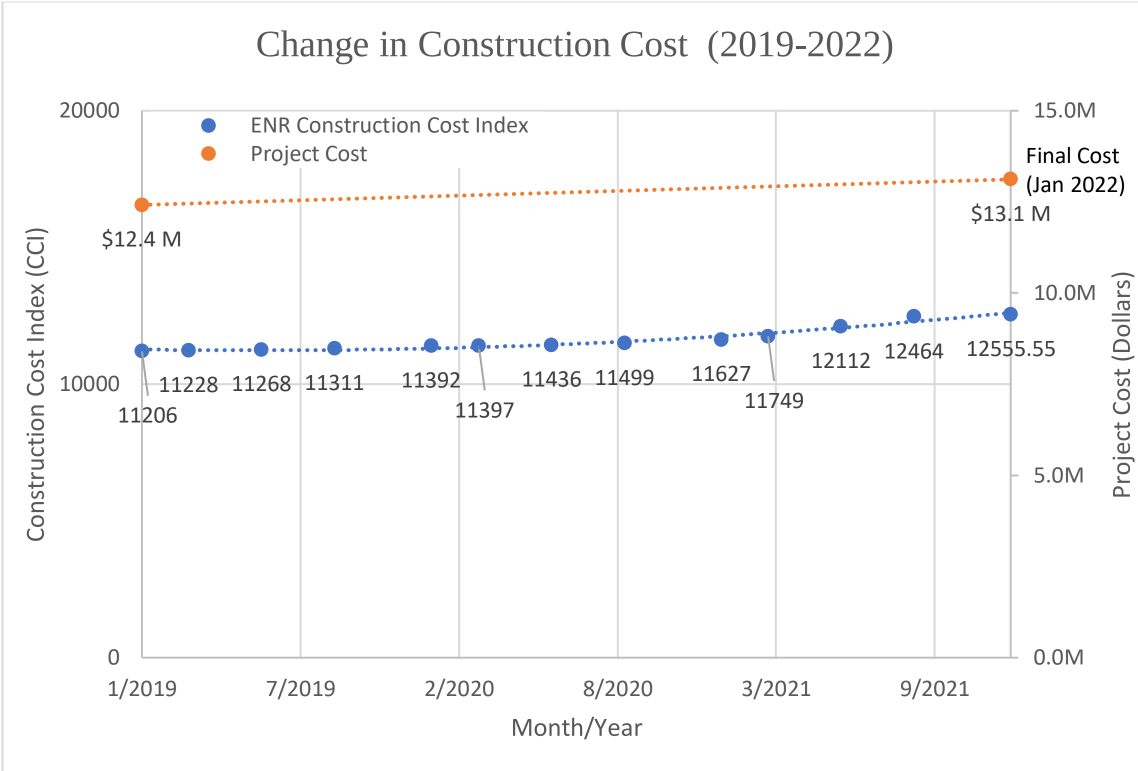


*Figure 12. Change in CCI and Change in Project Cost*

While the increase in CCI from 2019 to 2022 was 12%, the project's increase was 6% shown in Figure 12. The project was able to avoid some of the increases that influenced an overall increase in CCI. Since the project's cost increase was lower than that of the CCI and final cost was within GMP, the project performed well considering the con ditions at hand. The impacts of the COVID-19 Pandemic created unique constraints that the project operated in. All members of the project team faced and adapted to this new environment. The majority of typical pandemic related impacts were seen on this project to varying degrees. To the merit of all involved, the project showed resiliency in the face of adversity.

### 4.5.1 Risk Management

The Consigli team was also able to avoid some of the COVID related supply chain issues such as extensive lead times and shortages. Originally, the project was designed to be completed in two phases but was morphed into a single-phase project with an early turnover of the basement laboratory space. While the pandemic initially delayed the start of the project, the decision was made to proceed with purchasing equipment and materials such as the elevator, key HVAC equipment such as the ERU (Energy Reuse Unit), and windows. The elevator and ERU were stored offsite by the HVAC subcontractor Royal Steam. This proved to have been a wise decision as such specialized materials would likely have been heavily delayed if they were purchased within the standard procurement times. During a site walk, it was explained that one of the complications of the pre-purchase was that the warrantee had to be renegotiated as the ERU had sat for an entire year. The pre-purchase and storage cost Consigli more at the time however, this was a small expense compared to the possibility of an extensive wait. Specialty items such as the ERU, elevator, and windows cannot easily be sourced and their absence would negatively impact the project schedule.

### 4.6 Safety

Safety is an integral part to all construction projects. The presence or lack thereof of safe work conditions, good practices, and housekeeping can mean the difference between a successful project and one that results in potentially life altering consequences.

The Kaven Hall Renovation project had an excellent safety record. Health and Safety of all involved on the project was prioritized. Consigli's own goal was S.A.F.E (Staying Accident Free Everyday) [62]. During each OAC meeting, the project superintendent started off with a safety update. Site safety plans are only effective when followed properly. Consigli's "Predictive Solutions" safety auditing technology system was used to analyze site safety habits and behavior as well as to anticipate/avoid potential incidents.[62] These audits were performed on a regular basis and the site scored well. During walkthroughs, any unsafe conditions and practices were noted and quickly rectified. Due to Consigli's robust safety culture, these instances were rare and minor in nature. Checked often and with an eye for detail, issues were not able to develop into major incidents.

Communication between parties played a large role in safety. The owner, WPI, had provided safety guidelines and documentation to the General Contractor Consigli. Consigli then prepared site specific safety plans as well as collecting plans from subcontractors for submission to the owner and their inhouse safety team (EHS) for review. Constant communication of safety plans occurred in the planning phases and during construction. Sufficient prior notice of disruptive activities was given to WPI who would review the plans and create communications to advise the campus community. During an interview with WPI Facilities Director of Design and Construction Nick Palumbo in March 2022, Consigli's communication and safety record were commended [63].

Steps were taken to make sure the trades would be working in an environment free of as many hazards as possible. Prior to any demolition work, samples of items to be removed such as floors and walls were taken. These samples were tested for toxins such as lead and asbestos. Even in the absence of these toxins, workers wore proper personal protective equipment (PPE) such as respirators to avoid inhaling dust. To gain an understanding of how building materials behaved, small sections of walls were demolished. This allowed the widening of doorways to be conducted more safely. The brittle terracotta blocks that made up the corridor walls were found to crumble unevenly and unpredictably, which could have led to a collapse. Due to this, temporary shoring was installed to allow for a more controlled removal.

Keeping members of the public safe is as important as workforce safety. While project personnel are likely required to be well versed in safety protocols, members of the public are not. They continue to carry out their business around the project sometimes oblivious of its existence or potential hazards. Situated on an active college campus, Kaven Hall abutted one of few ways for students to access campus from the lower elevation on Boynton Street. The building was closed during most of the renovation, but in later stages the basement labs were opened for use. Disruptive work was scheduled for when the building was closed or unoccupied. With careful planning, the project team implemented temporary fire-rated doors that allowed students access to the lab spaces while sealing it off from active construction on upper floors. Signage was placed in order to reduce confusion, allow for the smooth flow of pedestrian traffic, and identify safe entrances and exits. Clearly marking access points helped cut down on the number of individuals wandering the site where they could accidentally enter a work zone.

## 4.7 BIM, Construction Technology, and LEED

In modern construction projects, there is an increased push towards to adoption of sustainability, the use of BIM and information technology, and lean design and construction principles. The Kaven Hall Renovation project was focused on improving building performance with respect to accessibility and energy efficiency, but LEED Certification was not a goal due to the added complexity of working with an aging building envelope. While LEED was not a goal, the installation of new windows and doors were reduced the amount of energy lost by the way of drafts and leaks. The toilets and bathroom fixtures in the building were fully replaced with a goal of higher water efficiency. In addition, new energy efficient lights, fixtures, and HVAC units were installed in the building.

### 4.7.1 Information Management

The use of technology in construction has the potential to create more efficient projects. During the renovation of Kaven Hall, technology was used to manage project information and help avoid costly discoveries later in the project. The primary piece of information technology used on this project was Procore. As discussed in a previous section, Procore served as a central management information system for the project. Means of tracking and control were not fully implemented into the system. Processes such as RFIs and related logging were implemented into Procore. Procore offered the ability to integrate a Primavera project schedule into their portal but this functionality was unused. The schedule was updated offline in Primavera P6 scheduling software then uploaded as a PDF to the project portal. According to Procore, when an updated schedule is uploaded, it must have the same filename as the previous. If it does not, lookahead schedule activities and other items may become inadvertently duplicated [64].

#### 4.7.2 Site Investigation Tools

Technical tools such as computer simulations and onsite scanning were also used for detecting physical conflicts. These tools were mostly used in the pre-construction phase, with the intention of enabling construction to continue better informed and with fewer disruptions. Light Detection and Ranging (LiDAR) was utilized to survey and map out existing conditions. This was successfully used to scan the spaces above ceilings, which helped the design and installation of mechanical, electrical, and plumbing (MEP) systems. LiDAR scanning was primarily utilized as a means of collecting information about existing conditions above the drop ceilings. This data was used be used to create a BIM model in Revit that could be later used to determine physical constraints of the project. The large amount work that had to be replaced meant a very complex layout with little room for error. If not caught beforehand, resolving a physical clash in the field would incur cost to both labor and materials.

Based off the floorplans, a 3D Revit model was also created during the design phase of the project and kept as a reference. The additional use of BIM could have alleviated issues regarding numerical data such as quantities or measurements. By design, BIM software like Revit and even drafting software like AutoCAD have the ability to create material schedules that specify how many of each item are needed based off of what was designed. This would have greatly assisted in the area of quantity takeoffs, estimating, procurement, and installation. An example of where this could have helped was the occupancy sensors and light fixtures. In an OAC meeting, there was discussion over if there were enough light fixtures and different kinds of occupancy sensors available. Had an accurate BIM or model been maintained, a quantity takeoff or itemized material schedule could have been quickly prepared. Additionally, constructability concerns regarding ADA compliant minimum radiuses for wheelchairs could have been checked ahead of time rather than in the field.

A case of where additional LiDAR scans could have caused savings would be in rooms KH202 and KH203. A drop ceiling that was installed during the 1980 renovation was initially identified to remain. It was later discovered during an inspection that the above-ceiling height was not to code and needed to be reworked. Had this been discovered earlier, the ceiling could either have been designated to be demolished and replaced or fitted with proper fire suppression coverage.

Ideally, the constraints would have been accurately modeled and MEP clash detection could be utilized to lessen the chance of physical conflicts in the field. A BIM model is only as good as the data that makes it up and must constantly be updated to remain relevant. Several shortcomings on this project could be attributed to either failure to maintain an active BIM model, inadequate data, or neglecting to utilize the model fully.

Prior to the installation of the elevator, the optimal location had to be found. The use of Ground Penetrating Radar (GPR) allowed for the nondestructive investigation of conditions below the concrete floor. The project team was able to site, excavate, and install the elevator pit and structural supports without encountering obstacles like hidden pipes or excess embedded rebar.

This type of testing was also successfully conducted with minimal disruption to occupants in the building. The noise and dust created by traditional methods such as concrete coring was mitigated.

The adoption of these techniques allowed the project team to avoid some potential problems and gain a better understanding of the building's existing conditions. However, these tools could have been implemented more extensively. The main pitfall of these tools is that they were used in the pre-construction phases but were not used to address changes in the project. Added scope items that were not initially included in the design phase did not benefit from clash detection. As an example, the tempered water loop for the emergency eye wash stations, conflicts were found in the field during installation.

The implementation of sustainability, the use of BIM and information technology, and lean design and construction principles are important to the future of the industry. While the Kaven Hall Renovation project did not utilize all of these, the ones that were utilized were not fully implemented for maximum benefit. The complexity of this project and the added items throughout its duration may have benefitted from a more thorough use of technical tools.

## 4.8 Project Scheduling – Primavera

Project scheduling was carried out using the Oracle Primavera P6 software package. Some of the key hallmarks of Primavera is the ability to plan, projects run schedule simulations, forecast project performance, and analyze costs and resource utilization [65]. Like any tool, it can only deliver the potential performance if utilized fully.

### 4.8.1 Work Breakdown Structure

The essential component of a Primavera schedule is the WBS (Work Breakdown Structure). This is the hierarchical outline that defines phases of the project. Groups of activities are identified by the order that they are to occur on the project. Within those, smaller activities are assigned an ID, name, and duration. Together, these build much of the schedule. From the WBS, the Gantt chart and other tools can be generated. The WBS and relationships such as predecessor and successor provide the necessary linking and sequencing between groups of activities.

### 4.8.2 Application of Primavera

The project scheduler in charge of building and maintaining the Kaven Hall Renovation Project's Primavera utilized the correct WBS methods. However, the schedule is missing key information that would help better predict and manage the project schedule and budget. One of the main features not utilized was the ability to assign resources to tasks. Resources can represent people, departments, groups, suppliers, contractors, etc.  By assigning resources to a task, it is possible to keep track of each subcontractor or group and their tasks.

## 4.9 ProCore

ProCore was an extremely helpful information management system used by the Consigli team throughout the Kaven Hall Renovation to centralize all documents and keep all parties informed with the most up to date information. This program was one of the most important tools used by the OAC parties during the construction phase. Organizing and storing all project documents in a centralized location allowed all project contributors to easily search, find, and review every detail regarding their specific work items. The mobile function allowed every project member to use ProCore and its features anywhere. ProCore assisted in the efficient transfer of information to keep everyone current to sustain momentum and prevent unnecessary delays or costly mistakes.

One of the key features within ProCore that helped Consigli during the construction phase was the Request for Information (RFI) tool. An RFI is a formal request for information from the contractor to the owner to resolve information gaps, eliminate ambiguities, and capture specific project decisions [66]. This process was originally done face to face and took a lot of time to complete. Modern technology like cell phones and email sped up the process but a lot of attention to detail was still required. The RFI manager was required to double check all steps, track RFI progress, and carefully organize all submissions, responses, revisions, and supporting docs. The process was still very time consuming and contained many points of failure.

To resolve these issues, ProCore facilitated and streamlined the process. When creating an RFI within ProCore, a pre-created form with all the most important details to be filled in appears. ProCore automatically assigns a number to the RFI and the RFI Creator fills in the details. The most important fields are:

- Subject; descriptive title
- Due Date, date RFI must be responded by
- Assignee, person responsible for responding
- RFI Manager, person responsible for overseeing an RFI
- Responsible Contractor, contractor responsible for work in question
- Received From, specific person with the question
- Distribution List, people who should be notified of RFI but do not fall into assignee category [67].

These fields provide each RFI with general descriptors, specific parties required for the resolution, and those that must be notified. Once these fields are completed the RFI Creator can enter the specific question and attach any relevant documents. The RFI Creator can then "Create as Open", which will automatically send out an action required email to the Assignee and an "RFI Created" email to the Distribution Members. An RFI can be created or responded to anywhere due to ProCore's mobile abilities. This process significantly speeds up the RFI creation and response times, allowing the contractor to receive direction with little time wasted. The software also logs and organizes all RFI's to create an easy to find record within the RFI Project Tool feature. There anyone with access can review the RFI, all connected emails, and the RFI Change History. This eliminates time spent previously on organizing and managing all RFI's and prevents any from being lost or deleted. If a deadline is missed, ProCore will automatically email all parties responsible for the RFI. This feature saves the RFI manager some time and ensures no RFI goes missing. This safety net guarantees all items are completed and prevents a missing RFI from being discovered later during the project where it can severely impact the cost and schedule.

The average duration of an RFI for the Kaven Hall renovation was approximately 10 days greater than the industry average due to unidentified items that needed replacement but primarily pandemic related issues. The average duration of all 243 RFI during the Kaven Hall renovation project was 20 days while the industry average is between 6.4 to 10 days [68]. The RFIs were organized by total duration to identify items with the longest duration. As displayed in Table 5 below, a total of 192 RFIs met the average industry standard of 10 days, the following 37 added an additional 5 days to the average, and the last 14 items added another 5 days to the average. The items with the greatest impacts were commonly addressed OAC meeting roadblocks and include ceiling issues, eyewash station, fan coil unit, HVAC, and lighting.

| RFI Metrics | | |
|---|---|---|
| AVG Duration | (Closed date – initiated date) | 20.09 |
| Industry AVG | | 6.4 – 10 |
| AVG over industry | | 10 days |
| | | |
| # of RFI's that | reach 10 days avg | 192 |
| | Reach 15 day avg | 229 |
| | | |
| | Add 5 days to avg | 14 |
| | Primarily roadblock items | Ceiling issues<br>Fan coil unit<br>HVAC<br>Lighting |

*Table 5. RFI Metrics*

All work items were impacted by the pandemic, which in turn increased the RFI durations. Since the project was originally expected to start in 2020, a few RFIs were created in the first half of 2020, see Figure 13. This is the case for the ceiling issues with an RFI duration of 385 days and the chilled water lines with an RFI duration of 65 days. Pushing back the construction start date meant that closing these 2020 RFI's were not the greatest priority. The ceiling issues were included several rooms and also changed several times due to discoveries and changes during construction. Therefore, it could not be closed any earlier as it was consistently changing. The HVAC system subcontractor was Royal Steam, which was severely impacted by the pandemic. This made it difficult to contact them, and response times were affected.

The RFIs for unidentified items that were eventually replaced primarily consisted of broad items like the ceiling issues and lighting. These two RFIs cover several rooms and consistently adding to them as new room ceilings and lights were selected for replacement increased the overall RFI duration. If these two RFI categories were assigned to specific room, then the creation of the first RFI would not be the initiated date for an RFI for a room that was added late in the construction process. This would have greatly reduced the total RFI duration but would also create more work for the project management team as they create new RFIs for each room.

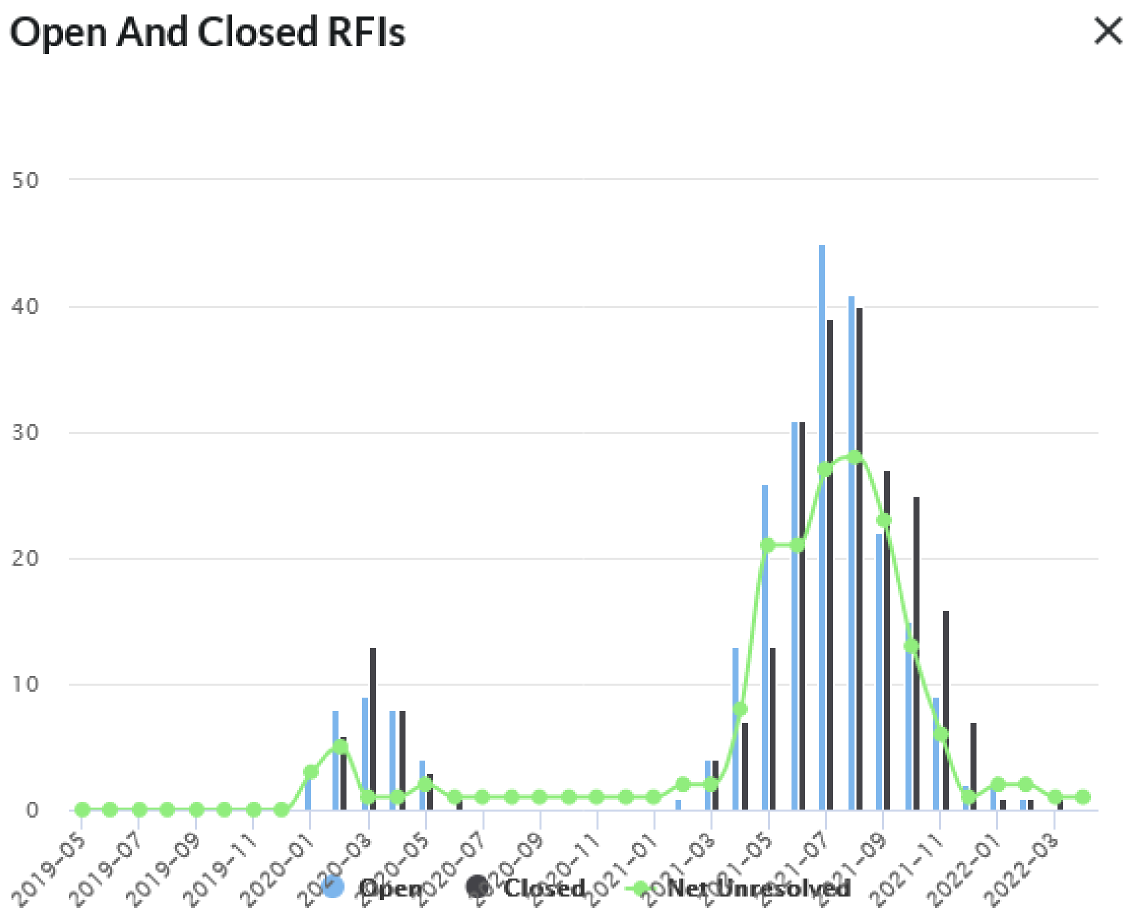


*Figure 13 Open and Closed RFIs Graph*

During the final stages of the construction phase, ProCore greatly facilitates the closeout process with the Punch List Tool. The Punch List is a list of items of remaining issues that need to be fixed before the project is considered complete.[69] Similar to the old RFI process, creating and closing a punch list was once very time consuming and required a detail oriented process to track and organize each item. Punch List items also require a more detailed description so the issue can be identified in the field by the party responsible for fixing the issue. The Punch List Tool in

ProCore was developed to address these issues by streamlining the process, organizing documents, and improving communication.

The Punch List tool was designed to be used in the field, and ProCore recommends using the mobile version. There are two options to create a Punch List Item. One is to select the Punch List tool icon and tap on the plus icon. The second is through the Drawings tool. Simply select the drawing to add the Punch List item, select the punch pin in the toolbar, and tap the location. Both options lead to the same New Punch list. This list allows the user to "Create Punch Without a Template" or to select a category from a WBS category list. When selecting from the WBS category list, a series of customizable templates appear. These templates include default information to help standardize data entry for common punch list items and save time when logging reoccurring issues [70]. After selecting the template, a New Punch window appears with certain fields already filled out that can still be edited. This window contains similar fields to the RFI creation process. It allows the creator to select a Punch Item Manager, Final Approver, Assignees, and Distribution Members that will be notified. It also allows the creator to describe the item, take a picture of the issue, and select any related attachments. After completing the form, it is saved and sent to the Punch List Item manager to review and assign the item. The Assignee will receive a "Ball in Court" notification to perform the work. The "Ball in Court" field identifies the party responsible for performing the next step in the workflow [71]. Once the work is completed, the "Ball in Court" moves to the Punch Item Manager to review the work and mark the Punch Item as "Ready to Close". This moves the "Ball in Court" to the Final Approver, who will review the item and select "Close the Item" if it meets project standards or tap on the Assignee and select "Work not Accepted". If not accepted, the "Ball in Court" goes back to the Punch List Manager. They will communicate with the Assignee to resolve the item and follow the same process to close the item. All these activities are automatically stored within each Punch List Item profile within the Punch List tool display table. This provides easy access to all Punch List items and eliminates the need for the Punch List manager to spend time organizing and managing all Punch List items.

The Punch List tool also provides several key performance indicators and charts to assist the construction management team with overseeing Punch List Items. These metrics include the Average Response Time, Total Overdue Punch List Items, Status, and Items by Assignee Company. The Status of Punch List Items is a graphic displaying the percentages of items that are closed, ready to close, and ready for review. This provides a visual representation of the percentage of outstanding and completed items. This graphic helps the management team to know the proximity to completing all Punch List items and it is supplemented by the Total Overdue Punch List Items number. This is a simple total of all overdue items. The Average Response Time provides info regarding how quickly to expect an item's completion. Each company will have a target goal for the average response time, and that goal may change depending on the status of the project. If the Average Response Time surpasses the target goal time by too much, then punch list items will take more time than desired and may impact the project schedule. Therefore, it is important that the management team keeps the Average Response Time reasonably low. The Items by Assignee Company is a bar chart displaying the number of Punch List Items each Subcontractor has open, closed, and overdue. This graphic identifies the progress made by each subcontractor to close their Punch List, and it also notifies the project management if any subcontractor is falling behind with their Punch List. This information allows the PM to address any possible issues a subcontractor is having and develop a plan for resolution.

Although there is no industry standard punch list duration, the total average for the Kaven Hall project was determined higher than normal due to difficulties associated with renovations and pandemic impacts. As displayed in Average Punch List Data in Table 6 below, the Total Duration was approximately 32 days, almost 6 times the ProCore recommended 5-day duration. The Resolved Duration was approximately 13 days, and the Days to Close were approximately 19. The trades took longer than usual to resolve their items due to schedule pushbacks from unforeseen conditions and pandemic impacts that rippled through the schedule. However, the biggest factor in the extended average duration was the project management team closing Punch List items after their resolution. This is partially caused by the preselected closeout days since the PM team cannot mobilize after each punch list item is completed. However, this long duration identifies how busy the PM team was in responding to unforeseen conditions and pandemic impacts that consistently impacted the schedule. They could have redirected their attention to reduce the Days to Close duration, but it would reduce their attention to more important project factors that have greater impact on the schedule and cost.

| **AVG Punch List Data** | | | | |
|---|---|---|---|---|
| Total Duration | Days past due to close | Resolved duration | Days past due to resolve | Days to Close |
| Closed - Created | Closed – Due | Resolved – Created | Resolved – Due | Total Duration – Resolved Duration |
| 31.89 | 26.89 | 12.58 | 7.59 | 19.31 |

*Table 6 AVG Punch List Data*

Submittals are vital to ensure that the completed work is in accordance with the project specifications developed by the design team, and the entire process is detail oriented, time consuming, and susceptible to mistakes. A submittal refers to information provided by a contractor to the general contractor that is then submitted to the design team for approval of equipment, materials, etc. before fabrication and delivery to the project site [72]. This process is required for almost every work item, and the Kaven Hall Renovation had 567 submittals [73]. Pulling the information form the specification section and submitting to the design team takes a lot of time and provides several possibilities for mistakes. Compound that with the fact that each subcontractor may not submit the similar looking forms, and the reviewing process becomes significantly more difficult. There is also no guarantee that every necessary submittal was created, and if they were all returned. These issues make the submittal process very difficult and time consuming. These issues were addressed with ProCore's automated upload capabilities, standardized process, and centralized storage location.

ProCore's Submittal Builder tool is the quickest and most accurate way of creating submittals [74]. The Submittal Builder is done from the Specification tool after all project specifications are uploaded. Simply select all spec sections, click the "Generate Submittal Register," and ProCore will then parse through every specification. Once the submittals are ready for review, click the link and ProCore will redirect the user to the Submittal Builder within the Submittals tool. On the left, ProCore displays all spec section divisions, sections selected by the user to build submittals, and a preview of how many sections ProCore found from each section. Here, the details of each submittal can be viewed and edited in case ProCore did not recognize any key details. Submittals can be duplicated or deleted in accordance with the project needs. The description of each submittal is extracted directly from the text within the spec section, and it can be reviewed with a link that directs to the specifications. This review allows the user to double check that the Submittal Builder included all the necessary information, and to include what was missed. After reviewing the submittals in the spec section, clicking "Confirm" will add them to the Submittal tool. The final step is to add additional information and the workflow to each submittal. This can be done in bulk with submittal packages to so all parties can manage and be notified about all submittals in bulk instead of individually [74]. Within the Bulk Edit Submittals in Package page, a standardized page similar to the ones seen when filling out an RFI or Punch List item is presented. ProCore recommends filling out responsible contractor, lead time, required onsite date, submit by date, location, submittal workflow, distribution list, and any other additional information [74]. When done, simply confirm the changes, and then click “Send Now”. This will send a digest email to the submitter. All these submittals are organized and stored in the Submittals tool within ProCore for easy access.

ProCore’s submittal builder addresses all the issues previously encountered with submittals with a centralized storage location, streamlining, and standardizing the process. The automated upload feature significantly saves time and allows for an easy double check of the work. The standardized process makes all submittals look the same. This makes the reviewing process much easier since all forms will look the same, and the information never moves around the page. The organized central location saves time when filing and searching for submittals. All these improvements allow project staff to focus on other more important issues instead of spending a lot of time organizing, filing, and monitoring the submittal process.

The Average Submittal Approver Response durations was the only ProCore metric that almost achieved the average days to complete. As displayed below in Table 7, the average duration to approve a submittal was approximately 11 days, while the average number of days to complete was approximately 8. That a Due Date average variance of approximately 2 days. This was a very impressive response time from the design team.

| **AVG Submittal Approver Response** | | |
|---|---|---|
| AVG Duration | (Returned date – Sent date) | 10.73 |
| AVG Days to Complete | (Due date – Sent date) | 8.41 |
| AVG Due Date Variance | (Returned date – Due date) | 2.32 |

*Table 7 Average Submittal Approver Response*

#### 4.9.1 Analysis

The only feature on ProCore not entirely used on throughout the Kaven Hall Renovation project was the Schedule tool. The schedule was uploaded to ProCore at the start of the project in 2020, but it was not updated on ProCore since. When asked about this during our interview, the Project Manager, Mark Suscovich, stated the scheduling aspect was not as functional as the construction team wanted it to be. This was due to a few factors that made it less efficient to use ProCore. First, the schedule was frequently adjusted due to material delays and unforeseen conditions. These factors were out of the construction team's control, and they adapted to each surprise as it was encountered. Second, the schedule was originally created and adjusted in Primavera P6, and then uploaded to ProCore. Uploading the schedule after every change can become time consuming and it would send notifications to everyone working on the project. Receiving too many schedule updates can make it difficult to identify the most recent schedule, and the construction team members can become confused due to this overcommunication. Any confusion on the project can further impact the schedule and ultimately affect cost. Therefore, to better control the channels of communication, Consigli only used Primavera P6 and issued that schedule to both subcontractors and the owners.

## 4.10 Quality Control

An important part of construction projects is the careful monitoring of the quality of work being carried out. The quality of work influences both owner satisfaction and safety. Throughout the project, multiple forms of quality control were carried out by the team.

The most basic form of quality control was observations by field engineers and other members of the construction team. Regular site walks following OAC meetings allowed for multiple parties involved in the project to visually inspect and discuss design decisions and review the progress of work. Typically the site walks included the project manager, superintendent, owner's project manager, architect, and interior designer. Subconsultants also occasionally made site visits to verify that work was completed as specified and to resolve technical issues in the field. In addition to site walks, quality inspections were carried out when applicable by project personnel and external parties. On this project, UTS (Universal Testing Services) of Massachusetts was contracted to inspect rebar and concrete placements. Adherence to standards of material quality and accuracy with the project specifications were checked.

An issue that arose in this project was the responsiveness of some of the sub-consultants and their ability to make site visits. In the case of Synergy, the MEP sub-consultant, the OAC team had reached out repeatedly in response to an open RFI that required a field visit to resolve. Occasionally, the visits could not be scheduled within the required timeframe. As a stopgap measure, "remote" inspections were conducted via videoconference or phone. While these may have sufficed for smaller issues, this limits the level of detail of inspection. Photos can be uploaded and cataloged in Procore, but the sense that comes from being onsite is still missing.

## 4.11 Project Changes

During the duration of this project, a large number of changes were made. Changes could be added or removed from the original project scope. In some cases, they were made to preserve the original cost and scope. They were also made in response to requests by the owner or other parties. A large source of changes was the existing condition of the building and systems which differed from what was originally anticipated.

### 4.11.1 Project Postponement

The largest change to this project was the postponement due to the COVID-19 Pandemic. This changed not only the schedule but cost and scope too. Originally, the project had been planned to be completed over the duration of two summers (summer slammers). Between the postponement in March 2020 and remobilization in May 2021, the project evolved to be a single-phase renovation with an early turnover of the basement water quality lab. The change in project phasing meant that the building and the classrooms and labs inside would no longer be accessible for use for at least the fall semester of the 2021-2022 academic year. The postponement also incurred costs that increased the total original contract sum for subcontractors to increase by 3%. Nearly every subcontractor submitted a change request for the cost of postponing the project from 2020 to 2021 as seen in **Error! Reference source not found.**.

| **Subcontractor 2020-2021 Postponement Cost Requests** | | |
|---|---|---|
| **Project Phase** | **Subcontractor** | **Description** |
| Final Cleaning | KO Stone | N/A |
| Demolition | Riggs Contracting Inc. | Postponement Costs - Demo |
| Sitework | Northeast Contractors Inc. (NCI) | CR028 2020 to 2021 Postponement Costs |
| Finish Carpentry | Riggs Contracting Inc. | Postponement Cost - Finish Carpentry |
| Waterproofing | Acme Waterproofing Co., Inc. | CR028 2020 to 2021 Postponement Costs |
| Doors/Frames/Hardware | Riggs Contracting Inc. | Postponement Cost - DFH |
| Glass & Glazing | Salem Glass Company | CR028 2020 to 2021 Postponement Costs |
| Drywall | Clifford & Galvin Inc | CR028 2020 to 2021 Postponement Costs |
| Acoustical Ceilings | K&K Acoustical Ceilings Inc. | CR028 2020 to 2021 Postponement Costs |
| Flooring | Business Interiors Floorcovering | CR028 2020 to 2021 Postponement Costs |
| Painting | Kaloutas Painting | CR028 2020 to 2021 Postponement Costs |
| Misc Specialties | Automation Solutions, Inc. | N/A |
| Elevators | OTIS ELEVATOR, USA | CR028 2020 to 2021 Postponement Costs |
| Plumbing | Harold Brothers | CR028 2020 to 2021 Postponement Costs |
| HVAC | Royal Steam Heater Co. | CR028 2020 to 2021 Postponement Costs |
| Electrical | Brattan Industries | CR028 2020 to 2021 Postponement Costs |

*Table 8 Subcontractor Requests for 2020-2021 Postponement Costs*

#### 4.11.2 Scope Change and Subcontractor Cost Increases

The final project pay requisition was analyzed for the invoices where individual sub-contractors itemized their costs for billing. Line items from the original project scope, change orders, contingencies, holds, and allowances were listed as well as the cumulative totals. These values were extracted to create a log of project phase changes and to track increases from the original contract sums. The tables were utilized to aggregate the data and support observations from OAC meetings and other research that may have identified problematic items.

Changes in the project were not evenly distributed across the different phases of work and their respective subcontractors. The cumulative total of change orders increased the original contract value for all subs by 73%, accounting for an 11% increase in the entire project's sum. As the scope increased, the areas of work required to accommodate those changes would increase in cost. Table 9 shows that the top 5 areas of the largest increase in cost were HVAC (275%), Painting (149%), Plumbing (109%), Demolition (109%), and Electrical (79%).

| Project Phase Changes | | | | | |
|---|---|---|---|---|---|
| **Project Phase** | **Increase from Original Contract** | **Change Orders** | **Contingency** | **Hold Transfers** | **Premium Time Claims** |
| HVAC | 275% | 22 | 4 | 5 | 3 |
| Painting | 149% | 9 | 2 | 4 | 4 |
| Plumbing | 109% | 6 | 4 | 0 | 11 |
| Demolition | 85% | Not Itemized | 0 | 0 | 0 |
| Electrical | 79% | 15 | 4 | 8 | 9 |
| Drywall | 62% | 9 | 3 | 3 | 9 |
| Flooring | 47% | 6 | 0 | 1 | 3 |
| Doors/Frames/Hardware | 45% | 6 | 0 | 0 | 0 |
| Finish Carpentry | 36% | 3 | 0 | 0 | 0 |
| Glass & Glazing | 27% | 11 | 4 | 0 | 0 |
| Misc Specialties | 19% | 2 | 1 | 0 | 0 |
| Elevators | 12% | 1 | 1 | 1 | 1 |
| Acoustical Ceilings | 8% | 5 | 0 | 0 | 3 |
| Final Cleaning | 7% | 1 | 0 | 0 | 0 |
| Waterproofing | 6% | 1 | 1 | 1 | 1 |
| Sitework | 3% | 4 | 1 | 1 | 0 |

*Table 9 Project Phase Percent Changes from Greatest to Least*

| Project Phases Listed in Order of Descending Cost | | | |
|---|---|---|---|
| **Order (Decreasing Cost)** | **Project Phase** | **Subcontractor** | **Increase from Original Contract** |
| 1 | Electrical | Brattan Industries | 79% |
| 2 | HVAC | Royal Steam Heater Co. | 275% |
| 3 | Demolition | Riggs Contracting Inc. | 85% |
| 4 | Finish Carpentry | Riggs Contracting Inc. | 36% |
| 5 | Drywall | Clifford & Galvin Inc | 62% |
| 6 | Plumbing | Harold Brothers | 109% |
| 7 | Painting | Kaloutas Painting | 149% |
| 8 | Flooring | Business Interiors Floorcovering | 47% |
| 9 | Sitework | Northeast Contractors Inc. (NCI) | 3% |
| 10 | Elevators | OTIS ELEVATOR, USA | 12% |
| 11 | Glass & Glazing | Salem Glass Company | 27% |
| 12 | Acoustical Ceilings | K&K Acoustical Ceilings Inc. | 8% |
| 13 | Waterproofing | Acme Waterproofing Co., Inc. | 6% |
| 14 | Doors/Frames/Hardware | Riggs Contracting Inc. | 45% |
| 15 | Miscellaneous Specialties | Automation Solutions, Inc. | 19% |
| 16 | Final Cleaning | KO Stone | 7% |

*Table 10 Project Phases and Subcontractors Listed in Order of Descending Cost*

When the list of sub-contractors and project phases is listed in decreasing total value, the phases with the largest percentage increase were not necessarily the most expensive as depicted in Table 10. However, Electrical, HVAC, and Demolition appear within the top 5 on both lists. From this observation and the number of change orders, it can be hypothesized that these were the most problematic and prone to change areas on the project. HVAC and electrical lead in the area of most change orders. Areas that were reported to have run into unforeseen conditions in OAC meetings such as electrical and plumbing have a high number of claims for premium time (additional time worked outside the scheduled hours) [75]. A lack of knowledge of pre-existing conditions is often a driver of project changes. As mentioned in the BIM/Construction Technology section, HVAC and MEP encountered issues regarding added scope items. Initial site investigations did not account for the potential for added work. Thus, the benefit of clash detection was not applicable to much of the work. Additional time had to be spent in the field correcting conflicting utilities or special constraints. When issues like these occur in critical areas, customer satisfaction may be impacted.

#### 4.11.3 Changes Impacting Customer Satisfaction

The change that most impacted customer satisfaction was the early turnover of the basement water quality lab. In an interview with the former environmental lab manager, it was revealed that many of the necessary amenities for lab operation were not present at the time of early turnover [76]. Relating to the lack of knowledge of existing conditions, it was previously assumed that the existing fume hood ducts in the lab were sufficient. Later inspections done during construction found that the ducts had been severely corroded by years of exposure to chemicals that they were not designed to handle. As a result, the ducts had to be replaced. This burden fell within the HVAC category. The early turnover of the lab space occurred later than anticipated. Originally it was expected in October but was delivered in November while lacking equipment such as functional fume hoods, heating, working eyewash stations, and natural gas for Bunsen burners. According to the lab manager, this limited the use of the lab to 1 MQP group. Others had to remain in scattered temporary spaces in Gateway Park and Sagamore.

# 5.0 Results & Analysis

The key findings from the Project Management Review sections were summarized and compiled. The lessons learned from each section are presented. This section serves as a steppingstone to the final results and recommendations.

### 5.1.1 Contract Structure

The Construction Manager at Risk with a Guaranteed Maximum Price was determined as the best contract and project delivery method to address all Kaven Hall project-specific factors. This contract let WPI select their preferred contractor that provided additional professional expertise. The GMP established a price ceiling and set aside funds for allowances and contingencies. Since all renovation tasks were built on pre-existing conditions, reserving funds for problems that arose throughout the lifetime of the project accelerated the problem resolution process.

### 5.1.2 Organization Breakdown Structure

The temporary elimination of the OBS hierarchy greatly contributed to team building but reinstating the OBS hierarchy to select a solution allowed the project to continue progressing forward. While the OAC Organization Breakdown Structure for the Kaven Hall Renovation project reflected a typical construction OBS. The typical OBS structural hierarchy instantly faded when a problem was encountered, and all team members entered open discussions on possible solutions. The best idea was recognized and addressed by the OPM, Jeff Lussier, and a more detailed discussion followed, until the OPM stepped in, reinstated the hierarchy, and selected the course for action to keep everyone engaged and maintain the project momentum.

The literature review provided the project team with information on problems commonly encountered during renovations and recommendations for mitigation. This research provided insight into which Kaven Hall problems were common in other renovations and which were specific to Kaven Hall. It also provided several renovation recommendations that the project team analyzed and compared to the solutions witnessed during the Kaven Hall project. Developing a list of problems and recommendations allowed the project team to identify gaps in the recommendations and create a comprehensive list of recommendations that are useful for future projects.

### 5.1.3 MQP Review

The Engineering Economics analysis of past MQPs revealed that the project cost was within an acceptable range. While the estimates did not seem initially accurate, extrapolation of the data and the application of the concept of future value resulted in projected costs that were close to official numbers prepared by the design team. The project duration as initially planned was also quite close to the estimated values. This further suggests that the project is within budget but over schedule.

### 5.1.4 Site Investigation Technology

Technology such as LiDAR scanning, ground-penetrating radar, and BIM were used to enable later work. However, these tools were not used to their full potential and were confined to items identified in the original scope. Several shortcomings on this project could be attributed to either failure to maintain an active BIM model, inadequate data, or neglect to utilize the model fully.

A concern was that ordering more detailed LiDAR scans and surveys of existing conditions would not result in worthwhile savings. While it is not feasible to complete an exhaustively detailed survey, more attention could be put towards historically problematic areas where existing knowledge of the building is lacking. As an example, it was later discovered that the above-ceiling heights in several rooms were not to code and needed to be reworked. If discovered earlier, the ceiling could have been specified to be replaced or fitted with proper fire suppression coverage.

Coordinating the use of the BIM model with project personnel or subconsultants with knowledge of fire protection design could also have benefitted the project. This project faced several issues that involved compliance with fire codes. A large component of this was attributed to the existing fire suppression system and coverage. MEP clash detection was successfully utilized in earlier work on the project, but to a lesser extent on added scope items. The BIM model could have been better used for quantity takeoffs for the project.

#### 5.1.5 Information Management

ProCore was the information management system used by Consigli throughout the Kaven Hall project that increased efficiency with improved communication and automatic data organization in a centralized location. This program specifically streamlined the Request for Information (RFI), Submittal, and Punch List process. The same ProCore features that facilitated these processes made the Schedule tool unusable. Schedule changes automatically notify all parties. Frequent schedule changes cause overcommunication that makes it difficult to identify the most recent and causes confusion. Therefore, the ProCore capabilities that streamlined the RFI, Submittal, and Punch List process also made it disadvantageous to upload a constantly changing schedule.

# 6.0 Conclusion

The professional project team adapted and responded well to the pandemic impacts, unforeseen conditions, growing project scope, and delivered a project within the GMP (Guaranteed Maximum Price). However, the project schedule was extended by a duration of six months as the Certificate of Occupancy was not issued as originally expected. This was a result of material shortages that led to difficulties getting ahold of the equipment including the Fire Panel Annunciator, a non-code requirement requested by the Worcester Fire Department later in the project.

Proactive PM decisions in response to pandemic impacts such as selecting alternatives when possible, and the early purchase and storage of materials and equipment aided in preserving as much of the original project schedule and cost as possible.

A growing scope was expected due to unforeseen conditions common in renovations. The project faced three specific types of unforeseen conditions. Unidentified items that required replacement, unforeseen difficulties discovered along the way, and unidentified pre-existing conditions. These different types of unforeseen conditions were addressed with a CM at Risk with a GMP contract that reserved funds to address issues discovered along the way, providing additional expertise, while guaranteeing a maximum contract value.

The analysis of the Kaven Hall renovation project and other case studies led to the creation of recommendations for future work. While the project was completed within budget, there were areas for improvement in terms of schedule and customer satisfaction.

# 7.0 Recommendations

1. More detailed assessment of building equipment to identify replacement needs before scope setting.
2. Early identification of requests from the Authority Having Jurisdiction that prevent the issuance of the Certificate of Occupancy.
3. Critically weigh the potential risks and rewards of conducting varying levels of site investigation.
4. Incorporate trades in the iterative design process to address constructability issues.
5. Use the BIM model to better anticipate quantitative data on the project and to coordinate with personnel/subconsultants with knowledge of code compliance.
6. Identify requirements for functional lab usage and reevaluate the feasibility of early turnover if requirements cannot be met.
7. Early identification of inter-building utility constraints.

## 7.1 Recommendation for Implementation

1. More detailed assessment of building equipment to identify replacement needs before scope setting. Departments administration should implement regular surveys for faculty and members to report needs. The condition of buildings and equipment should be more frequently inspected. A record of items to be replaced should be kept and worked into the renovation no matter how minor. An example is the scratched cabinets in the water lab.

2. Early identification of requests from the Authority Having Jurisdiction that prevent the issuance of the Certificate of Occupancy. Open channels of communication with the local

AHJ early in the project design phase. Ask for input and identify any code and non-code requirements so they can be properly addressed.

3. Critically weigh the potential risks and rewards of conducting varying levels of site investigation. While exhaustively detailed surveys and LiDAR scans of a building are impractical, more attention should be paid to historically troublesome issues. For example, the above ceiling heights should be checked on the next renovation. Considerations for added scope should be worked into the pre-construction investigation plan.

4. Incorporate trades in the iterative design process to address constructability issues. While a design may work on paper, its real-world implementation may not be realistic. Connecting the design team with the construction trades creates a holistic problem-solving approach that identifies constructability issues early enough to prevent expensive rework.

5. Use the BIM model to better anticipate quantitative data on the project and to coordinate with personnel/subconsultants with knowledge of code compliance. BIM models should be regularly updated to reflect a “living model” of the building. As work progresses and scopes change, the model should be updated accordingly. Important dimensions for ADA compliance and fire code should be verified on the model and onsite by individuals with a working knowledge of the codes. Quantity takeoffs should be estimated with the design in BIM, then verified on the project. This mitigates the need for some guesswork.

6. Identify requirements for functional lab usage and reevaluate the feasibility of early turnover if requirements cannot be met. Project stakeholders and the OAC team should be in open communication with lab managers, professors, and researchers who understand the

minimum requirements for lab functionality. Work to determine thresholds that must be met for easy lab turnover.

7. Early identification of inter-building utility constraints. Existing building utilities have consequential influence on the M/E/P systems installed during a renovation, and the identification of a utility constraint late in the construction process can require expensive rework. Unlike other pre-existing conditions, inter-building utility constraints are easier to identify if a whole-systems approach is implemented early by the OAC team to account for inter-connected buildings.

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