Gilbertville Mill Restoration Project

A Major Qualifying Project

Submitted to the Faculty of the

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Abstract

This project is a plan for implementation of a 2009 UMASS Amherst Master's Thesis to redevelop the site of a mill in Gilbertville, MA. The goal is to take the site, which contains several 19th century buildings that serve a diminished purpose in today's economy, and turn it into a living, modern, artistic community center. The project team will explore all relevant design considerations and use the associated standards to determine the viability of the plan. Furthermore, the team will design any necessary changes to the structural system of the mill and provide a cost estimate of them all.

Capstone Design Statement

Gilbert, George Manufacturing Company Mill No. 4, referred to as Gilbertville Mill No. 4, is a currently under-utilized, historical warehouse that is currently undergoing the process of restoration at the hands of the Salem family, who are the current owners. The architectural plan for the building's renovation revolved around turning the warehouse, which is currently exclusively used for storage, into an urban, multi-purpose facility. Gilbertville Mill No. 4 consists of three buildings attached to one another at the ends, and the floors of each individual building would have its own unique use in accordance with the conceptual plan. To do so, it would be necessary to ensure that the building would actually be capable of supporting the loading that would accompany a change of use. Taking the architectural renovation forward, the next step for the Salem family was to determine the feasibility of such a plan, and that is where this particular project comes into focus. Before beginning the team determined that the architectural plan would need to be revised if any part of the plan failed to meet compliance with building codes or if any structural element experienced failure under the proposed new loading. The approach taken by the project team to solve this problem consisted of five main steps in order to come to conclusive results, and those are as follows:

1. Condition assessment
2. Code review
3. Structural Analysis
4. Structural Design
5. Cost Analysis

The steps taken throughout this project were intended to develop designs of structural building systems that would help bring the building to compliance with structural and fire safety aspects of applicable building codes, namely the International Building Code. The following is a list of ABET criteria that, as per the "Civil Engineering Commentary" from ASCE, this project needed to meet.

Economic

One of the major limiting factors of the designs the team recommended was cost. A cost analysis was performed for the upgrade of structurally deficient building members and for several options of a floor framing layout. For each area of design, the team made sure to provide at least several options, whenever possible. Doing so would gave the owner the choice to select a system that had its advantages along with an associated cost. Each design solution comprised of several different options in terms of building materials as well. The process of providing different options in materials took into account the cost per square foot and weight of material that would be necessary to maintain a satisfactory level of performance.

Environmental & Sustainability

When choosing building materials to implement for the various design areas, wood and steel were both chosen, although steel was only chosen for a select few areas. The team considered the sustainability of each material, among other topics, in a literature review that was intended to provide an insight behind some of the initial decisions that were made. The effect that the production and procurement of each material was considered at this stage.

Social

This project had a social impact, albeit an indirect one. The proposed development plan for the mill was intended to convert the currently under-utilized storage building into a multi-purpose, modern facility that the Gilbertville village community can all come together to enjoy.

Safety & Political

Safety considerations for this project were obtained from the International Building Code (IBC). The IBC, in addition to other building codes and ASCE 7-10, were used to check building compliance in terms of structural and fire safety requirements for different types of occupancies. This check was a manner of ensuring that the building, when fully renovated would be capable of performing satisfactorily.

Manufacturability

Manufacturability, or constructability, addresses the need for global economy in the design. This is a factor that must be designed for, and it influences decision making at all steps of the process, from selecting a framing system to the actual system design. A design that is constructible is one that takes the least to detail and implement, and constructability itself focuses on topics such as framing layouts and the number of pieces needed in an area of framing. By providing a range of design options that were each individual in their own sense, the team accounted for this demand.

Professional Licensure Statement

A Professional Engineer has the ability to sign and seal engineering plans, thereby ensuring public health and safety. PE licensure is considered to be the highest standard of competency in the engineering profession, and so, any person with this title is responsible not only for their work, but also for the lives affected by the work that is performed. Licensure requirements were first enacted in Wyoming in 1907, and since have been instituted in every state of the country.

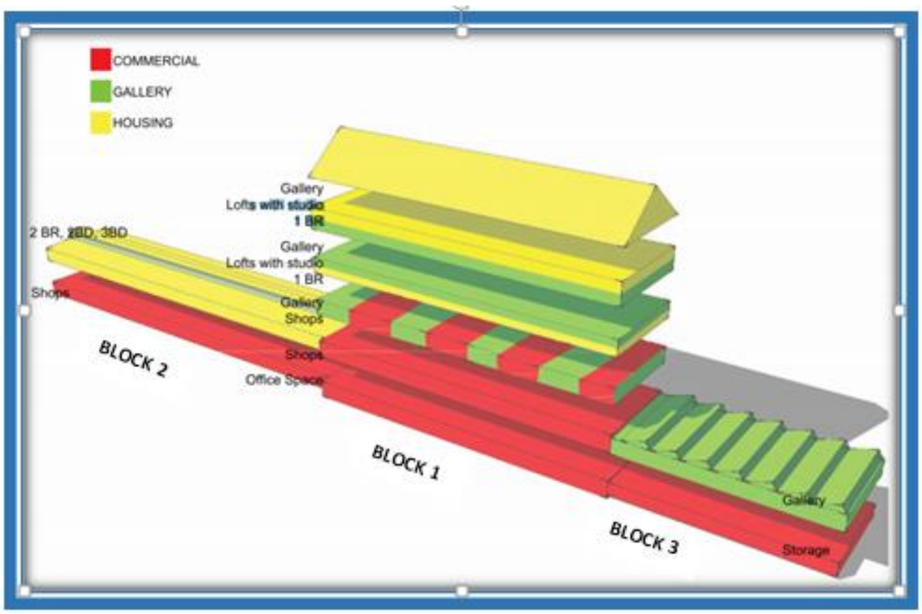
There are a set of steps an individual seeking professional licensure may follow, the first being to earn a four-year degree in engineering from an ABET accredited school. Once a Bachelor's of Science degree is obtained, the individual would go on to become an Engineer Intern by successfully passing the Fundamentals of Engineering (FE) exam. Once this step is completed, the next would be to find work that would provide the engineer with at least four years of professional experience. While doing so, the engineer should take time to become familiar with the licensure requirements of his or her state. Finally, the last step to obtain licensure is to sit for the Principles and Practice of Engineering (PE) exam and successfully complete it. The process does not just end with completing the PE exam. A set of requirements must be followed to maintain this license, and these generally vary from state to state. Many state licensing boards require that PEs maintain and improve their skills through continuing education courses and other opportunities for professional development.

Government agencies, educational institutions and private industries are beginning to require that employees obtain licensure at some point in their professional careers. The PE license tells the public that the engineer in question has not only mastered critical elements of the profession, but has also become competent enough to offer services directly to the public. Licensure helps upkeep the prestige of the profession, as PEs are respected by the public and are held to the same regard as professionals in other career fields. But to the individual, becoming licensed enhances reputations and leads to more opportunities for career development.

Executive Summary

Mills and factories were the mark of a time period where power-driven machinery was a main source for producing various goods in North America. However, other countries soon had their own Industrial Revolutions, causing for a shift in economic climates, and most major manufacturing industries abandoned the U.S. for developing countries. These mills, now un-profitable, no longer fulfilled a practical purpose. The Gilbert, George Manufacturing Company Mill No. 4, hereinafter referred to as Gilbertville Mill No. 4, was no exception. Built in 1867, the textile mill served to process raw cotton that came in from the nearby railroad that ran from Boston, MA to Albany, NY. The building, now under-utilized, has outlived its main economic purpose.

Mr. Richard Salem and his family, the current owners of Gilbertville Mill No. 4, decided that, rather than demolish the building, it would be better to transform it into an urban community center. Upon coming to this decision, the Salem family enlisted help to begin the process of renovating the mill. Shehla Hussain, a 2010 Master of Architecture candidate at the University of Massachusetts, Amherst developed a proposal that would not only revive the economic value of Gilbertville Mill No. 4 but also allow it to better serve the community of Gilbertville, a small village located in the town of Hardwick, Massachusetts. Hussain's conceptual design for the mill was intended to recreate the environment of a typical outdoor urban community, which would be housed within the existing building. It fosters a sense of space both inside the building by removing the floor in places and allowing residents to look down and see the goings-on of lower floors and outside of it by providing a large patio where residents can enjoy, among other things, a view of the Ware River.



Gilbertville Mill No. 4 consists of three individual buildings named Blocks 1, 2 and 3. Block 1, also known as the Clock Tower Building, is a five-story structure. Blocks 2 and 3, known as the picking building and the dye building respectively, are both two stories in height. The three buildings are connected to one another at the ends, and currently, each is primarily used for manufacture and storage. The tentative design of the mill would first involve changing the occupancy of the mill from an exclusively storage use to a mixed use of housing, commercial, and exhibition gallery purposes. Each individual floor of the different buildings would be dedicated to one of these three uses. Following the change of occupancy, the architectural plan also introduces several unique renovations to the site. One such renovation included transforming the currently bare fourth floor to a gallery area, where several mezzanines encased by glass walls hang from the floor above. Here, it was the architect's intention to allow gallery viewers to observe artists as they worked.

The main goal of this Major Qualifying Project (MQP) was to take the conceptual plan and compare it against the existing structural capacity of the building. Options for renovation could then be designed and that would allow the team to determine a cost for the conceptual plan. After that, the team and Mr. Salem could then come to a conclusion on whether or not it was feasible to implement Hussain's renovation plan. Before beginning any analysis work, the MQP team developed a set of project objectives that were intended to help outline the work that needed to be done, and they are as follows:

- Determine the necessary structural capacity of Gilbertville Mill No. 4
- Create a model of the building with which a structural analysis will be performed
- Check the requirements against the capacity and determine areas where renovation is necessary
- Conduct a code review to assess if Gilbertville Mill No. 4 is in compliance with the structural and fire safety aspects of applicable building codes
- Provide a cost estimate for the repair of structurally deficient members in the building

To begin the fulfillment of these goals, the team conducted a condition assessment, in which measurements were taken during a tour of the mill buildings. At this time, structural elements were checked for their load bearing condition. The dimensions of each structural member and the spacing from one element to another was measured, checked against existing plans of the mill and used in the structural analysis of the mill.

The team ultimately concluded that there were two categories in which the proposed plan for the mill would need to be revised, one being that the plan could fail to satisfy standards set by relevant building codes. The other category considered structural members failing to perform under the loading expected due to a change in occupancy. The first category was accounted for by conducting a code analysis, in which the International Building Code and the International Existing Building Code were primarily utilized to ensure life and building safety. This encompassed determining building requirements for means of egress, accessibility and fire protection systems. In instances where the second category was encountered, it was then necessary to develop a new system that would satisfy the requirements for capacity.

The redesign of the building's loading pattern provided the unique challenge of having to meet the new requirements for construction and also keep the building's current aesthetics consistent. This factor, along with the constructability of the recommended design, were the main parameters used in selecting a suitable design that could be implemented in each area of the buildings that needed renovation. The range of choices provided for the various areas of the building where the elements were structurally deficient was dependent on the nature of deficiency and usage of the element. Areas that were considered to meet the strength criteria were kept the same size and dimension, and simply a known and possibly better quality of wood was used. Most other areas were allowed a range of options from different qualities of Douglas-Fir Larch timber to a common class of Glue-Laminated (Glu-Lam) timber. Steel was provided as a third option in one area of the building where Douglas-Fir Larch timbers and Glu-Lam timber were both unable to meet the load requirements. The steel structural elements, however, would be out of place in the area they were recommended for, causing for a clash with the current aesthetics and leaving the choice to be purely subjective.

The MQP team's main deliverables for this project consist of a set of design solutions for the building elements that would fail under new loading conditions proposed by the conceptual plan. These design solutions consider options for different types of materials and provide the associated cost. The team also provided Mr. Salem with recommendations on the steps necessary to take in order to move forward with the renovation of the mill.

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1 Introduction

With the end of the 18th century came the beginning of the American Industrial Revolution, a period of time which saw the development of new forms of business that involved the use of power-driven machinery. Such machinery was put to use in factories and mills used to produce various products and goods.

As of current day, however, many mills stand idle, vacant due to economic shifts and advancements in science and technology. Rather than allow these mills to remain abandoned many entrepreneurs have made a business out of repurposing the old industrial space into usable commercial, office, and residential space that is more suited to today's economy. This is a concept that is not new in world of architectural design. Examples of this practice can be found in the creation of The Massachusetts Museum of Contemporary Arts, MASS MoCA, from an industrial complex in North Adams, Massachusetts and in the creation of Custard Factory, in Birmingham, UK, from a series of manufacturing buildings that were used to produce custard. Both of these examples make great use of the large amount of flexible space provided by the typical layouts of manufacturing buildings by becoming modern, open-ended platforms for people to use to relate to an audience.

One such building is located in Gilbertville, Massachusetts and Richard Salem, the proprietor, came to the team with this kind of transformation in mind. Previously an architectural student at UMASS Amherst had drawn up a plan for Gilbertville Mill No. 4 as her Master's thesis and created a vision that Gilbertville Mill No. 4 could again be a vital part of the small town of Gilbertville. Now, the plan is to see what it would take to make that vision a reality. In this paper, the team explores all relevant design considerations based on a condition assessment of the site, determines the viability of the plans based on the current structural capacity of Gilbertville Mill No. 4, and proposes relevant changes to the plan if they do not meet the standards set by the various building codes or if elements of the building fail structural calculations and tests based on the new purpose and loading of the building.

Objectives

As the team developed a better understanding of the project, a set of objectives were created, and are stated as follows:

1. Determine the necessary structural capacity of Gilbertville Mill No. 4
2. Create a model of the building with which structural analyses will be performed
3. Check the requirements against the current capacity and determine areas where renovation is necessary

4. Conduct a code review to assess if Gilbertville Mill No. 4 is in compliance with the structural and fire safety aspects of applicable building codes
5. Provide a cost estimate for the upgrade of structurally deficient members in the building

2 Background

This section will provide an overview of all the topics that pertain to this project, beginning with a review of the history of the Gilbertville mill and a timeline of its ownership. Following, is a section on the current condition of Gilbertville Mill No. 4, as well as what the redevelopment plan entails. A subsection is included that compares the building materials that were considered in the design phase and lists the pros and cons of each. This chapter then finishes off with a section detailing the various building and zoning codes that will be analyzed, as they relate to this project.

Figure 1: Aerial view of Gilbertville Mill No. 4

2.1 History of Gilbertville Mill No. 4

The official name of the mill being renovated is as follows: Gilbert, George Manufacturing Company Mill No. 4 (MACRIS, 2016). Hereinafter it will be referred to as Gilbertville Mill No. 4. This building is one of four warehouse mills located in Gilbertville Village, Hardwick, Massachusetts. In 1991, Gilbertville Village was designated to be a historic place by the National Register of Historic Places. Being located within the boundaries of the Gilbertville Historic District, Gilbertville Mill No. 4 itself is thereby classified as a historic building.

The current buildings that make up the site were built at different times for different purposes. The first building, West 1, was erected in 1867 and the many floors of the building were used for combing, spinning, and carding of the wool. West 2, East 1, and East 2 were erected in the 1880’s and were used for picking, sorting, and cleaning, respectively. West 3 was originally erected in the 1880’s but it was torn down and replaced in 1914 with the saw-tooth-roofed Dye House. As the name suggests West 3 was used primarily to dye the wool.

The ownership and purpose of Gilbertville Mill No. 4 changed several times over the course of its life. In 1932, the Gilberts sold Gilbertville Mill No. 4, then declining in profitability, to Boston investors. Gilbertville Mill No. 4 was liquidated after the flood of 1938. It was then taken over by the Salem family and Gilbertville Storage Co. in 1950.

2.2 Current Conditions

Gilbertville Mill No. 4 currently consists of two separate buildings, referred to as West and East buildings.

The West building contains three blocks, and is closest to the Ware River. The first block is the middle one and it is referred to as West 1. It is made of a basement level and an attic, with four floors in between. West 1 also contains two auxiliary structures, the clock tower in the east and the toilet tower in the west, closer to the river. The block to the south, referred to as West 2, contains two floors, a basement and a one floor above that.

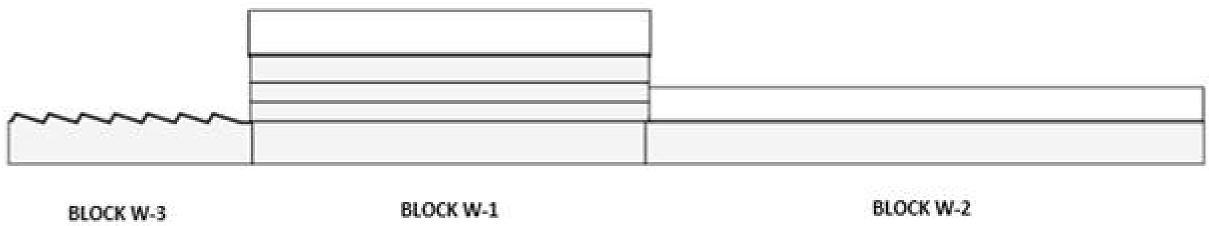

Figure 2: West Elevation view of West Building

West 2 is quite long compared to the other blocks, and makes up a significant portion of the overall building; the entire block is naturally lit by clerestory windows. The basement of West 2 appears to have had some work done to its structural system. Several of the elements appear to have been replaced with modern steel I-beams to help span places where openings in the column lines were required.

The block to the north, referred to as West 3, contains two floors, a basement and one floor above it. It was built last of the three blocks and was constructed in such a way, using a lot of steel and thick concrete slabs, as to be able to support heavy machinery.

The East building, further back from the Ware River, contains a two blocks which each have three floors. The northern block, referred to as East 1, contains clerestory windows that help light the interior. The southern block, referred to as East 2, does not have the same clerestory windows as East 1 and, as a result, is very dimly lit. This may have been on purpose to have a place to store the cloth in a place where it would not get damaged by the sun.

Much of the buildings are used for storage and many other miscellaneous purposes. Inside is everything from books and carriages to lumber and cloth.

Currently, the site, including the buildings and property, is estimated by the Town of Hardwick, which Gilbertville is a part of, to be worth $241,542.

2.3 Future Plans

The redevelopment plan for the Gilbertville mill, created as part of a UMASS Amherst Architectural Master's thesis, consists of redefining the purpose of Gilbertville Mill No. 4 into a mixed-use site that contains housing, commercial and public gathering areas. Currently, plans have been made to repurpose only the West building, while the East building has been left untouched.

The housing section of Gilbertville Mill No. 4 breaks down as follows: 5 units of 1 bedroom housing, 10 units of 2 bedrooms, 5 units of 2 bedroom duplexes, 2 units of 3 bedroom duplexes, and 30 units of lofts with studios. The commercial section of Gilbertville Mill No. 4 will be designated for offices, retail destinations and storage space for art and millwork. Lastly Gilbertville Mill No. 4 will consist of areas such as exhibition galleries and community lounges for public gatherings.

2.4 Structural Analysis & Design

There are two modern approaches for the design of structures: Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD). Both approaches are equally valid for the design of any structure and each approach has similar requirements. LRFD was the method chosen for the analysis and design phases of this project, and it is a design method that implements various load combinations, which can be found in applicable building codes or ASCE/SEI 7. In LRFD, the available strength of an element is referred to as the design strength and all LRFD provisions are structured so that the design strength must equal or exceed the required strength. This is presented in specifications as:

$$R_u \leq \varphi R_n$$

Where R_u is the required strength, determined by analysis of LRFD load combinations. R_n is the nominal strength which is determined according to applicable specifications, and φ is the resistance factor for a particular limit state. The product of φR_n results in what is known as the design strength.

2.4.1 Loads and Load Combinations

Before any structural design process can begin, an analysis needs to be performed. Such an analysis is intended to determine what loads already exist, and thus what loads a structure needs to support. These loads are typically dead and live loads, however other loads such as roof, snow, rain, wind and earthquake loads can exist in structures as well. After determining what loads are present in a structure, the required strength, (axial load, bending load, shear load, etc.) can be determined through utilizing a series of factored combinations, which are based on ASCE/SEI 7. A few of these load combinations are as follows:

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \ or \ S \ or \ R)$
3. $1.2\ D + 1.6(L_r \ or \ S \ or \ R) + (0.5L \ or \ 0.5W)$

The margin of safety for the loads is contained in the load factors and resistance factors. This margin is intended to account for unavoidable variations in materials and the changing nature of loads in a real-world environment. It is the decision of the designer to not only choose the appropriate load combination, because each combination takes different loads into effect. The appropriate load combination, the one that should be chosen, is the one that produces the greatest loading on the structure. If an inappropriate load combination was chosen, or if a load was multiplied by an incorrect factor, the produced required strength would be faulty, resulting in detrimental effects on the design of the structure.

2.4.2 Steel vs. Wood

It is important to give careful consideration to the types of materials that should be used for a project. Some structures are consistently made with one material, an example being how building foundations are typically made of concrete. Other structures however, can be built using a range of materials, and some materials can prove to be better choices than others.

One of the main materials that was up for consideration, only in specific areas, was structural steel. Structural steel is a category of steel used as a material for making structural shapes, such as beams, channels, angles or plates. These shapes are formed with specific cross sections and mechanical properties. Shapes such as I-beams have high second moments of area, which allow them to be very stiff in respect to their cross sectional area. Additionally, structural steel has high strength, stiffness, toughness and ductile properties, thereby making it a popular choice for commercial building construction.

Another material option was timber, namely Douglas-fir. Timber is strong, light and reliable, making construction simpler and safer than steel construction. The lightweight structures available in wood construction relate to reduced foundation costs and easier transport. Wood is an orthotropic material, meaning that it has three axes (longitudinal axis, tangential axis and radial axis) along which material properties can vary. Most wood properties for structural applications are given only for directions parallel to grain (longitudinal axis) and perpendicular to grain (radial and tangential axes). Timber is considered to be exceptionally strong, relative to its weight, and good detailing, coating and maintenance can help enhance the durability of timber structures.

A third material that was considered was Glu-Laminated wood (Glu-Lam), which is a type of stress-rated engineered wood that is composed of wood laminations that are bonded together with durable, moisture-resistant adhesives. Compared to steel, Glu-Lam is stronger, pound for pound, and it has greater strength and stiffness than similarly sized lumber (Engineered Wood Association, 2016). Glu-Lam has a versatile range of shapes, from straight beams to complex, curved members and it is available in both custom and stock sizes.

Safety

Wood is clearly a material that would fall susceptible to fire. As much of an issue this may be, building codes require that all building systems perform to the same level of safety. Therefore, with the assistance of sprinkler systems, fire-resistance-rated wall, floor, and ceiling assemblies, fire safety can be increased. Additionally, heavy timber has a particular advantage in the event of a fire. While the outer layer of a wooden element chars, the wood itself retains its strength and slows combustion and therefore allows for an adequate amount of evacuation time.

Due to the fact that steel is noncombustible, there is a reduced risk of fire to occupants, firefighters, and property or business owners. Steel is now fabricated and enhanced with fire protection, so that it can sustain greater temperatures before melting and deforming due to great increases in temperature. Steel framing will also not rot, warp, split crack or creep, all of which are modes of failure for lumber.

Cost

The cost of materials proves to be based on the geographic location of the project site. Other factors to consider when comparing different construction systems include the complexity of the layout, the site, builder experience, and relative material price at the time of erection.

Wood construction is beginning to make a return in modern building, and with that brings an increase in need and supply. Therefore prices for timber framing would be likely to be more stable for builders over a long term period. Such price stability is not as certain with other building materials, such as steel, which requires the consumption of fossil fuels for manufacture. The manufacture of steel is heavily dependent on a continued availability of cheap fossil fuels, which are unfortunately becoming a scarcity.

One major benefit of steel construction is the cost compared to traditional construction methods such as wood frames. Wood may be cheaper upfront, but steel will cost less over the span of a building's life, therefore making it a long-term solution. Typically, steel is fabricated off-site, and this reduces on-site labor, cycle time and construction waste. These factors result in a shorter construction time, which in turn allow for earlier occupancies and lower financing costs.

Material Availability

Approximately one-fifth of all land in the United States grows timber that could potentially serve a commercial purpose, so it is fair to assume that wood is a readily available material. The United States annually produces over 30 billion board feet of lumber. However, large forest fire, hurricanes and outbreaks of forest pests can damage forest lands and hinder the supply of timber supplies to local mills.

In 2015, the Iron and Steel Industry in the United States was the third largest producer of raw steel, and the industry produced 81 million tons of steel. Most steel in the United States is now recycled and made from scrap waste (U.S. Geological Survey, 2016).

Both lumber and steel are produced and manufactured in certain sizes, and while there are options to customize the size of the structural element based on specific need, a higher cost would surely ensue.

Efficiency and Structural Performance

Although wood construction is vulnerable to water damage, fire, decay, shrinkage and termites, it is a relatively lightweight material that easy to manipulate. In areas prone to high wind, wood is an ideal choice for construction. This is due to the fact that wood's elastic limit and ultimate strength are higher when loads are applied for short periods of time, as is the case for high wind situations. When structural panels are attached to lumber they form solid and stable roof, floor and wall systems, and when used to form diaphragms or shear walls, structural panels significantly increase the lumber's ability to resist high lateral forces (Forest Foundation, 2015).

Steel frames provide a significantly greater strength-to-width ratio than wood, and thus steel can be used for larger bays and wider frame spacing than wood construction. Increases in bay spacing and frame layouts in turn maximizes the amount of usable floor area for owners and tenants. Steel is also a resilient material, with high strength and ductility resulting in advantages over wood in events such as natural disasters, earthquakes, fires or blasts (Metal, 2015).

Sustainability

Apart from being a renewable resource, timber also has low production energy requirements and is a net carbon absorber. Forests that are well managed can produce timber on a continuous basis, while having negligible negative effects on soil and water in surrounding areas. However, as a global demand for lumber rises, increased harvesting has developed, particularly in tropical countries. The rate of harvesting has been steep enough to alarm scientists concerned with the ecological importance of these forests and the role that deforestation may play in global warming.

Steel is very durable and highly recyclable, making it an appealing material for construction. Steel framing results in less material waste than lumber, and even recycled steel loses none of its inherent properties.

2.5 Cost Analysis

Owners, contractors, architects, and engineers all rely on cost estimates during the construction process because they enable the estimator to place a monetary value on what the project is worth. When planning a project, costs can significantly over-run if correct estimates are not considered. As such, an accurate estimate is among the first steps in to undertake during a project. Cost estimates can be conducted in a variety of manners, one of which is through utilizing construction estimate reference books.

Developments in the construction industry are continuously monitored to provide reliable cost information. Construction costs can vary depending on general economic conditions; however, price fluctuations within the industry are reliant on many other factors such as city cost indexes and crew compensation. RSMeans handbooks are useful tools, because they track these factors from year to year, in order to provide the user with an up-to-date means of construction estimating.

3 Methodology

The Restoration of the Gilbertville Mill and the conclusions that the team reached regarding its feasibility was a multi-step process that involved a structural analysis of the members of the buildings, a trial-and-error approach to design, and a cost analysis that resulted in a set of practical options for the continuation of the project. Ultimately, the team developed two categories for which the renovation plan would need to be revised, the first being that the plan could fail to satisfy standards set by relevant building codes. The second category considered structural members failing to perform under the new loading proposed from a change of occupancy. The first category was accounted for by conducting a code review, while the second was accounted for by performing a structural analysis.

3.1 Code Review

The re-design of Gilbertville Mill #4 had to comply with all appropriate codes and standards to ensure the safety of the building. Building codes protect public health, safety and welfare by regulating the minimum requirements that must be met in the design, construction and maintenance of building and non-building structures (IBC 2015). Codes are merely intended to provide guidelines for design processes, and are thereby not to be held accountable in the event of a mishap made by the responsible designer or engineer.

3.1.1 Codes & Standards

The codes that the team examined were the *International Existing Building Code*, the *International Building Code*, the Massachusetts State Building Code, the Town of Hardwick Zoning Bylaws, and ASCE 7. Figure 3 shows that the team considered the *IEBC* to be the governing code of usage in this situation, since the project entailed a renovation. The IEBC addresses the repair, alteration, addition or change of occupancy in existing buildings. It is founded on principles that are intended to encourage the use and reuse of existing buildings, while also requiring for upgrades and improvements, within reason.

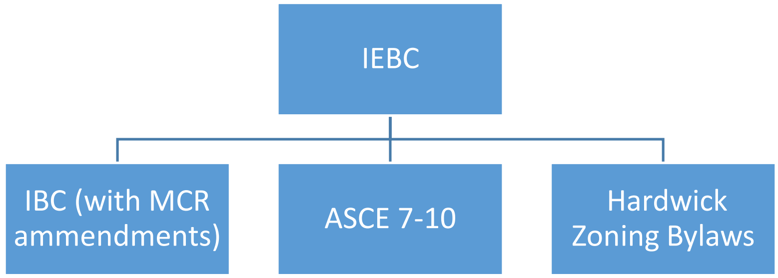

Figure 3: Hierarchy of use of applicable building codes

The IBC, ASCE 7 and Hardwick's Bylaws were used as references to the IEBC, and were therefore considered to be secondary. For repairs or alterations the IEBC was evaluated for any exceptions for historical existing buildings. But for any new construction, including any change of occupancy, the IBC had to be consulted for building requirements.

3.1.2 Building Space Requirements

Determining the occupancy classification for each area of Gilbertville Mill No. 4, as per the proposal, was the first step of determining whether the building would be capable of being successfully renovated. This determination would later allow the team to find the live loads that area of the building could expect to see during its life cycle.

Moving on from occupancy classification, the IBC AND IEBC also have provisions for the allowable height a particular occupancy may be above grade level, as well as an occupancy's maximum allowable area. These factors depend on the occupancy's type of construction, which is an assessment used by the International Code Council to rate that particular occupancy's resistance to fire. These rating range from I to V, where I is the greatest rating and therefore allowed the most leeway in terms of allowable building heights and areas. Construction Type V is the lowest rating in resistance to fire, so naturally this type would have in place the most building restrictions.

3.1.3 Fire Safety

The IEBC and IBC were also evaluated for fire safety requirements. Not only did this evaluation consider necessary fire extinguishing systems for each individual occupancy, but it also looked at requirements for various means of egress, occupant loads and the required number of exits per floor. These are all factors that could influence the evacuation time and survival outcome in the event of a fire in the building. The section of the IEBC that relates to fire safety also provides construction requirements

This section of the *IEBC* provides construction requirements regarding a building's level of fire safety, and any historic building that does not conform to the provisions of this code that constitute a distinct fire hazard must be given an approved automatic fire-extinguishing system, as determined appropriate by the code official. An automatic fire extinguishing system however, cannot be used to substitute for, or act as an alternative to, the required number of exits from any facility. To ensure both building and life safety, subsections regarding means of egress and automatic fire-extinguishing systems were evaluated.

3.2 Structural Analysis

This phase of the project consisted of conducting site visits, and performing load determinations and calculations, all of which will be discussed in further detail.

3.2.1 Condition Assessments

On the 26th of August, the team conducted the first of three site visits in which mill proprietor, Richard Salem, gave a tour of both the West and East buildings. During this first site visit the team took measurements of the heights, widths, diameters and on center spacing of the building's structural elements, such as columns, girders, and beams. The team visited the mill twice more, on November 16th and December 14th. These two site visits served to fill in any gaps in information that was necessary to begin the analysis, such as building materials, wall thicknesses, and floor thicknesses. Additional photographs of the various rooms in Gilbertville Mill No. 4 were also taken, to make for a more complete visual representation. After one site visit, the team received a disk from Mr. Salem that contained an AutoCAD drawing of the entire building as it currently existed.

Figure 5: W-2, W-1, and the Clock Tower, Picture taken during the first site visit in August.

Figure 4: W-2 and the East Buildings, as seen from W-1-5.

In addition to conducting a site visit, the team also contacted the Town of Hardwick to gather further information on Gilbertville Mill No. 4. Through this consultation, the team acquired field cards collected by town assessors that provide information on land and property areas, building dimensions, and years of construction, amongst other things.

Figure 6: The Saw-tooth roof of W-3

Figure 7: Inside W-2-1

The next step in the study was to design new structural members that were able to hold the proposed loading and wouldn't fail in bending, shear, or axial loading conditions. This step went hand-in-hand with the cost-analysis since a range of member sizes of various materials were considered and multiple cost estimation tools were used. The final step in the study was to go back to the structural analysis phase of the design and to recommend alternative solutions to the problems that involved, to a reasonable extent, changing the conceptual plan to fit the building instead of changing the building to fit the plan. A cost estimate was also completed for this step.

The next step in the structural analysis, and in being able to accurately assess the viability of the conceptual plan, was to visit the project site in Gilbertville. The ability to go to the site and get a first-hand account of the Mill allowed the team to have a better understanding of the challenges and scope of the project. Throughout project the team visited the site three times to either kick off the project at the beginning or to fill in the gaps in the team's knowledge with crucial information towards the end. Initially the team only planned on visiting the site twice, once as sort of a kickoff event for the whole project and once to take down necessary information after the project had gotten fully underway. The initial site visit took place on August 26th, 2015. This visit was intended as a tour and a chance for the team to see what they were really dealing with. The team took some measurements to get a preliminary understanding of the capacity of the building. The goals for the initial site visit included; gain a basic familiarity with the site, take notes and measurements of existing structural members and their condition, measure spacing between members, and to take note of story heights. The visit consisted of a walking tour of both the East and West buildings by Mr. Salem. From the visit the team was able to come away with reference photos, a history of the Mill provided by Mr. Salem, and preliminary measurements of many of the members in the buildings.

The team conducted two more site visits, one on November 16th, 2015 and another of December 14th. The primary objective of these additional site visits was to obtain wall thicknesses, floor thicknesses and what type of wood the building's structural elements were made out of. The team also received a set of files from Mr. Salem containing architectural plans and deeds of the building.

Design of the building's structurally deficient areas was undertaken with the intention to minimize cost and to closely adhere to the conceptual plan. Following the initial cost estimate, the team determined areas of the architectural plan that could be changed to significantly lower the cost of renovation and provide Mr. Salem with a range of options.

3.2.1 Load Determination

To get the loads that needed to be carried, the team determined the occupancy classes using the IBC and their associated loads. The occupancies of the building were determined mostly using Page 7 of the conceptual plan, shown in Appendix B. Then the team determined the loads associated with those occupancies using another table 1607.1 in the IBC, shown in Appendix C. Then, using plans provided by Mr. Salem and field measurements, determined the capacity of the various beams and columns in the buildings using the LRFD method laid out in the 2015 NDS for the wood members, "Appraisal of existing iron and steel structures" for cast iron columns, and the 14th edition of the American Institute of Steel Construction manual for the steel members.

Capacities of wood beams was calculated in accordance with NDS 2015, Load Reduction Factor Design (LRFD) method. In W-1-2, W-1-

Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor K_F	Resistance Factor ϕ	Time Effect Factor
$F_b' = F_b$	x	C_D	C_M	C_t	C_L	C_F	C_{fu}	C_i	C_r	-	-	-	2.54	0.85	λ
$F_t' = F_t$	x	C_D	C_M	C_t	-	C_F	-	C_i	-	-	-	-	2.70	0.80	λ
$F_v' = F_v$	x	C_D	C_M	C_t	-	-	-	C_i	-	-	-	-	2.88	0.75	λ
$F_c' = F_c$	x	C_D	C_M	C_t	-	C_F	-	C_i	-	C_P	-	-	2.40	0.90	λ
$F_{c\perp}' = F_{c\perp}$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	C_b	1.67	0.90	-
$E' = E$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	-	-	-	-
$E_{min}' = E_{min}$	x	-	C_M	C_t	-	-	-	C_i	-	-	C_T	-	1.76	0.85	-

Figure 8: Applicability of Adjustment Factors for Sawn Lumber

3, and W-1-4 the new loading was greater than the assumed capacity of the beams and only a relatively simple redesign was necessary. The new beams dressed dimensions were based off standard design values found in the NDS Supplement 2015. The chosen species was one that was most readily available in the area. The options of using an equivalent Glu-Lam beam was also given and based on design values from the NDS Specification 2015.

In W-1-5, the attic's structural system needed to be redesigned because the architectural plan did not account for the presence of the structural members in the design. The beams and their corresponding columns were moved and this created much larger spans between floor beams in some areas. Intermediate beams had to be added and different layouts were considered and either chosen or rejected based on cost.

In W-2-0 the conceptual plan calls for demolishing a load bearing wall in the basement of Building W-2. This resulting span that now needed to be designed for was twice as long as it was previously. One alternative would be to replace the load bearing wall with columns but that is not shown in the conceptual plan so if that was simply an oversight then the plan would be to put columns in the places they would be along the column lines. Steel is the preferred option due to its comparatively light weight when compared to the sizable wood beams that would to be installed instead of this. Sawn Lumber is not a viable solution because there is no commercially available size of sawn lumber that satisfies the requirements. Using Glu-Lam, the largest commercially available size of Glu-Lam timber satisfies the loading requirements, but would be very impractical. It would, however, keep the current aesthetic of a timber framed building.

Columns were also analyzed and designed using the LRFD method in accordance with the NDS 2015. The method of determining allowable loading for a column involved factoring the reference design values provided in the NDS Supplement by the relevant factors shown in Table 4.3.1 in the NDS. Using the LRFD Method, the reference design values assumed for Douglas-Fir structural members were multiplied by the Wet Service Factor (C_M), the Temperature Factor (C_t), the Size Factor (C_F), the Incising Factor (C_i), the Column Stability Factor (C_P), and the LRFD only factors which were the Format Conversion Factor (K), the Resistance Factor (φ) and the Time Effect Factor (λ). In case the case of this analysis, the Wet Service Factor (C_M), the Temperature Factor (C_t), and the Incising Factor (C_i) were all equal to 1 since the members would not be exposed to high temperatures regularly, were indoors and not exposed to excessive moisture, and were not incised to prevent damage by the elements. Through this method the team was able to determine which columns were and were not able to carry the new loading pattern. The columns that fell in the category of inadequate were those on W-1-0, W-1-1, and W-1-5.

After determining what live loads different occupancies could expect to experience in their lifetime, it was then possible to determine whether the building's elements were structurally capable of supporting those loads. The analysis of beams and columns both followed a similar process, but the structural elements were tested for different types of failure modes. The beams were evaluated for their moment and shear capacity and deflection, whereas the columns were tested for their maximum induced loading and slenderness.

The analysis process for both beams and columns began by evaluating the dead and live loads that were applied to each individual element. The live loads depended on the occupancy of the area where the element was located, and they were found through performing the code review. Dead loads, however, were found based on material properties and many values for the materials were taken from the *Boise Cascade: Engineered Wood Products* fact sheet.

3.2.2 Calculations

Although the team had no means to establish a certainty when identifying what species of wood was currently in place in the building, assumptions were made based off of architectural drawings received from the Salem family. The team did research on the different methods of wood identification and also looked into the different types of defects that can occur in wood over time such as the appearance of checks, splits, and rot in the members. To account for this setback, the team made conservative assumptions about the wood in the mill. The values used to for analysis purposes were the most conservative for the given species of wood that the team decided on. The rationale behind this was that this would be worst-case scenario and that the recommendations given at the end of this report could be treated as fairly comprehensive in terms of what parts of the building could possibly be in need of reinforcement.

3.2.2.1 Modeling

This project made use of 3-D Structural Modeling software as a tool to better visualize the building and the loads acting upon it. This visualization allowed the team to more accurately calculate the demands on the buildings. Originally, the team planned to use this Model to complete a full structural analysis of the Mill however the team was unable to properly link AutoDesk's Revit, the modeling software, to AutoDesk's Robot, the analysis software, to perform the calculations.

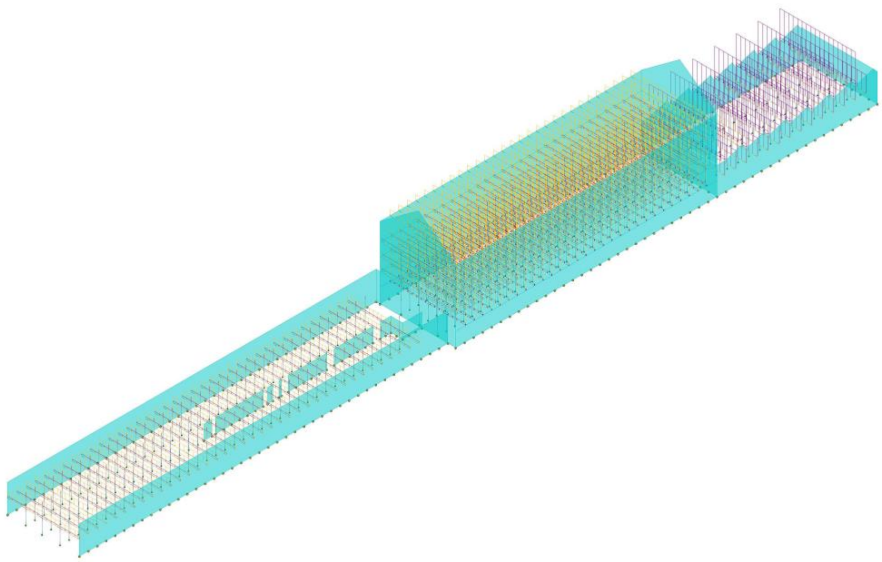

Figure 9: Analytic Model of Gilbertville Mill #4

3.2.2.2 Spreadsheets

Mainly due to the fact that the team was unable to get Robot to properly function, a structural analysis was done manually, using Microsoft Excel as the primary software tool to expedite the process. After conducting site visits, a spreadsheet was made for all of the beams in the building system, and another for all of the columns. Each spreadsheet was broken down by floor and the physical properties of each element were documented.

3.2 Structural Design

Design of solutions for the areas where the conceptual plan's loading exceeded the capacity of the existing members found within the buildings structural system was conducted in largely the same manner as the analysis with a few exceptions.

First, the design started with the loading that was going to be applied to the member and then worked backwards to determine the needed size of the member based on a given reference stress value. This workflow allowed the team to quickly calculate a large range of options for considerations and enabled an easy selection of the best for closer consideration.

Second, the solutions provided assumed a much larger design reference value from the *National Design and Specification Manual Supplement 2015* than the existing wood members. This value was chosen according to the quality of wood that was found to be most commercially available in lumberyards in the area.

Third, a range of options were provided, from Sawn Lumber to Glu-Lam to Steel, for every floor within all three buildings. If multiple grades of the chosen species of Sawn Lumber were available in the area and a cost was provided, then the calculations were done for those various qualities of wood. This range of options allowed the team to later optimize the cost of the renovations based on material costs.

3.4 Cost Analysis

Conducting a cost analysis was the next step of the study. Doing so allowed the team to determine which of the design options for a given area was the most financially feasible, this was the chief among the concerns presented by the sponsor.

4 Results and Analysis

After determining the necessary criteria for satisfactory structural performance, the team outlined what areas of the building needed to be focused on. This section presents the development of design process, the design options, and the rationale behind them.

4.1 Code Review

From the IBC code review that the team conducted, the multiple floors of Gilbertville Mill No. 4 were broke down into three primary occupancies: mercantile (commercial), assembly (gallery) and housing (residential) occupancies. Figure 10 below is a visual representation of this breakdown.

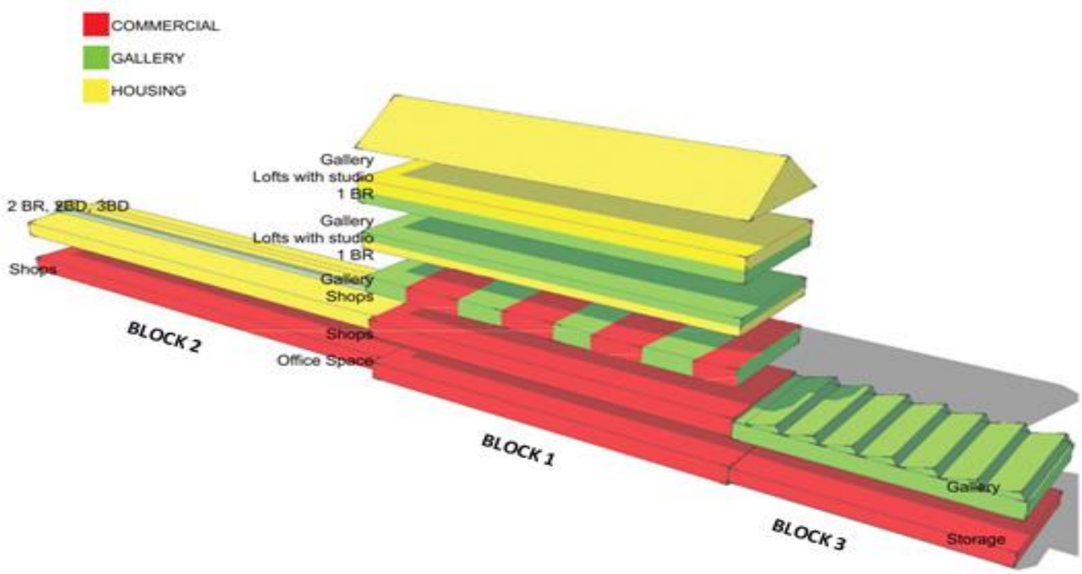

Figure 10: Gilbertville Mill No. 4 occupancy breakdown

According to the IBC, a building that is of mixed use and occupancy must be individually classified by portion. The change in use and occupancy of the buildings means that is necessary to make sure the plans take chapter of the IBC into account.

Group A (Assembly) is the classification applicable for the first and fourth floors of West 1 and the first floor of West 3. In regards to this project the gathering will be for recreational reasons but the area will be without fixed seating, such as it would be to view a movie or concert. Therefore, the sub-classification that is applicable to this project is A-3 since the art galleries, which will constitute the majority of the space, are specifically listed under Section 303.4 “Assembly Group A-3” in the IBC.

Group B (Business) will be applicable to the basement of West 1. It will fall into this category since it will be used as space for media offices and photo studios. These uses fall under the listed occupancy of Professional services in Section 304.1 “Business Group B” of the IBC.

The Group M (Mercantile) classification will apply to the basement of West 2 which will be used as a space for cafes and other food services as well as a market for the artists to sell what they have created. The Section 309.1 “Mercantile Group M” specifically lists markets as one of the occupancies that this classification could be applied to.

Group R (Residential) will be used to classify the first floor of West 2 and the attic, third floor and second floor of West 1. The sub-classification that will be applicable to this project is R-2, which refers to a space that contains more than two dwelling units and the nature of the occupancy by the residents is primarily permanent. The most suitable description for these dwelling units would be apartments, which is listed under Section 310.4 “Residential Group R-2” as a use that this classification could be applied to.

Group S (Storage) will be used to classify the basement of West 3 which will be used for storage of art supplies such as paper, canvas, paint, clay, and other things. Paper and canvas are listed under Section 311.2 “Moderate-hazard storage, Group S-1” because of their combustibility so S-1 will be used as the classification for the whole area.

4.1.1 Building Space Requirements

The three buildings that Gilbertville Mill #4 consists of appear to fall into Type IV construction and shall be checked for compliance. If the current structural system is non-compliant with Type IV, then Gilbertville Mill #4 buildings then we will check for the ways to make it compliant or, if that is not feasible, consider the building to be Type V.

After determining the type of construction for each occupancy classification, the allowable heights and the allowable number of stories above grade plane were found, in accordance with Sections 504.3 and 504.4 of the *IBC*. Allowable building areas were determined based on several factors: the type of construction, the occupancy classification, whether an automatic sprinkler system is installed and the amount of building frontage on public way. Building areas were also found in accordance with Section 506.2 of the *IBC*. Below, Table 1 displays this information in terms of allowable and existing values.

Table 1: Allowable Building Height, Number of Stories above Grade Plane, and Building Area

Building & Floor No.	Building Height (ft.)		Number of Stories above Grade Plane (stories)		Building Area (ft^2)	
	Allowable	Existing	Allowable	Existing	Allowable	Existing
Building W-1						
W-1-0	75	10	4	0	144,000	16,399.97
W-1-1	75	10	3	0	60,000	16,399.97
W-1-2	75	10	3	1	60,000	16,399.97
W-1-3	75	10	5	2	61,500	16,399.97
W-1-4	75	10	3	3	45,000	16,399.97
W-1-5	75	10	5	4	61,500	16,399.97
Building W-2						
W-2-0	75	10	3	0	82,000	20,052.74
W-2-1	75	12.25	5	0	82,000	20,052.74
Building W-3						
W-3-0	75	8.08	3	0	70,000	9,569.52
W-3-1	75	12.67	3	0	60,000	9,569.52

Allowable values were based upon a variety of factors, such as a floor's height above grade plane in terms of stories or the use of automatic sprinklers in the building. For each building, it was noted that no individual occupancy could exceed the height and number of story limits prescribed by the code. It was found that the seventy-five feet was the allowable building height of each of the mill building's intended occupancies.

For multistory buildings that have multiple occupancies, the code states that the governing allowable value is the most restrictive one. It should also be noted that occupancies with fire walls and fire barriers are treated as if they were individual buildings. Buildings that are adjoined or have access to a public way are capable of receiving an area factor increase but, as the areas of each of the occupancies was within the limits it was determined that an area increase was not necessary.

4.1.2 Fire Safety

The means of egress subsection states that existing door openings, and corridor and stairway widths less than those specified in the IEBC may be approved, provided there is sufficient width and height for a person to pass through the opening or traverse the means of egress. The minimum limits for means of egress are determined by adhering to Section 1012.4 of the *IEBC*. In order to determine the limiting values for egress systems, each occupancy was sorted with one of the five Means of Egress Hazard Categories. These hazard categories are in regard to life safety, and they range from 1 being the highest hazard, to 5 being the lowest.

Due to their original use, the floors of Buildings W-1, W-2 and W-3 of Gilbertville Mill #4 were all classified as occupancy group F-1, and that would have placed them each under Hazard Category 4. With the proposed renovation, floors of Gilbertville Mill #4 with occupancy classifications of A, M and R-2 would be identified under Hazard Category 3, while floors with B and S-1 occupancy groups would be classified under Hazard Category 4. Therefore, each occupancy has either risen to a higher hazard category, or has remained at the same level.

The IEBC has provided requirements for means of egress systems that experience a change in occupancy and a change in hazard category as well. For egress systems that move to a higher hazard category, Chapter 10 of the *IBC* must be adhered to, with few exceptions relating to new and existing stairways, corridor walls and dead-end corridors. When an egress system remains at the same Hazard Category, or moves to a lower one, existing egress elements must adhere to Section 905 of the *IEBC* while new elements are to follow Chapter 10 of the *IBC*.

Means of egress requirements were determined by considering *IBC* regulations on the number of occupants for whom the egress systems are provided. The number of occupants is also known as the occupant load, and this is the maximum expected number of people each occupancy can safely accommodate at a single time. Each occupancy has its own occupant load factor, in terms of either gross or net square feet. The floor area of each occupancy is divided by this factor to provide the occupant load.

Table 2: Gilbertville Mill No. 4 occupant loads

Building & Floor Number	Occupancy classification	Occupant load factor (IBC Table 1004.1.2)	Area (ft^2)	Occupant Load
Building W-1				
W-1-0	**B** Office	100 gross	16,399.97	164
W-1-1	**A-3** Gallery	30 net	16,399.97	547
W-1-2	**A-3** Gallery	30 net	16,399.97	547
W-1-3	**R-2** Apartments	200 gross	16,399.97	82
W-1-4	**A-3** Exhibition	30 net	16,399.97	547
W-1-4.5	**R-2** Apartments	200 gross	16,399.97	82
Building W-2				
W-2-0	**M** Retail	60 gross	20,052.74	335
W-2-1	**R-2** Apartments	200 gross	20,052.74	101
Building W-3				
W-3-0	**S-1** Storage	300 gross	9,569.52	32
W-3-1	**A-3** Gallery	30 net	9,569.52	319
Gilbertville Mill #4 Total			1576,44.34	2,756

As shown in Table 2, the total occupant load for Building W-2 would be the sum of the occupant loads of the building's two floors. Based on the proposed renovations it was found that the total occupant load of Gilbertville Mill #4 would be 2,756. Limiting conditions for the occupant load were found in Chapter 7 of National Fire Protection Association (NFPA) 101: Life Safety Code. These conditions stated that for any area less than 10,000 ft^2 (930 m^2) the occupant load could not exceed one person for every 5 ft^2 (0.46 m^2), whereas the occupant load could not exceed one person for every seven square feet (0.65 m^2) for any area exceeding 10,000 ft^2 (NFPA, 2015).

A capacity factor of 0.2 inch/occupant (5.1 mm/occupant) was used for calculating the capacity of stairways. For egress travel on stairways, the floor with the greater occupant load that was serviced by the staircase was considered. For other egress components, such as doorways, corridors, and ramps, a factor of 0.15 inch/ occupant (3.8 inch/ occupant) was used. The capacity factors were multiplied by the occupant load to obtain a minimum required clear width of components, in feet. These values are displayed below in Table 3.

Table 3: Means of egress for stairways and other components

Building & Floor Number	Occupant Load	Means of Egress – Stairways (ft)	Stairway Capacity (occupants)	Means of Egress – Other Components (ft)
Building W-1				
W-1-0	164	2.8	14	2.1
W-1-1	547	9.2	46	6.9
W-1-2	547	9.2	46	6.9
W-1-3	82	1.4	7	1.1
W-1-4	547	9.2	46	6.9
W-1-5	82	1.4	7	1.1
Building W-2				
W-2-0	335	5.6	28	4.2
W-2-1	101	1.7	9	1.3
Building W-3				
W-3-0	32	0.6	3	0.4
W-3-1	319	5.4	27	4.0
Gilbertville Mill #4	2756	46.5		34.9

After determining the occupant loads, the required number of access to exits was found. From Table 1006.3.1 of the IBC, it was found that stories with occupant loads between 1 and 500 people, a minimum of two exits per story was required. This applied to Buildings W-2 and W-3, and floors W-1-0, W-1-3 and W-1-4.5 of Building W-1. For stories with an occupant load between 501 and 1000 people, a minimum of three exits per story was required. This provision was applied to floors W-1-1, W-1-2 and W-1-4 of Building W-1.

The IBC was additionally evaluated to determine what kinds of fire protection features and systems would be required. Chapter 9 of the *IBC* specifies where fire protection systems are required, and applies to the design, installation and operation of such systems. Provisions regarding the installation, repair and operation of these systems can be found in the International Fire Code. In order for the allowable occupant loads determined for the building's means of egress to be applied, the building would have to be supplied throughout with automatic sprinklers.

Automatic sprinkler systems are required for construction in certain occupancy groups. For example, for Group A-3 occupancies, automatic sprinkler systems must be provided throughout the story where the fire area is located, and throughout all stories from the Group A occupancy to, and including, the levels of exit discharge serving the A-3 occupancy.

Table 4: Fire-extinguishing system requirements

Occupancy	Automatic	Carbon Detecting	Portable
Assembly	X	X	X
Business	X	X	X
Mercantile	X	X	X
Residential	X	X	X
Storage	X	X	X

Automatic sprinklers must be provided when the fire area exceeds 12,000 square feet (1115 m^2), the fire area has an occupant load of 300 or more or when the fire area is located on a floor other than a level of exit discharge serving such occupancies. The one condition for which a Group M occupancy would be required to have an automatic sprinkler system that applies to Gilbertville Mill #4 would be because fire area exceeds 12,000 square feet (1115 m^2). These specific provisions can be disregarded however, as each of the three buildings are required to be equipped throughout with automatic sprinkler systems. Sections 906 and 915 of the IBC also provide requirements for portable fire extinguishers and carbon monoxide detectors. In short, Table 4 displays what kind of fire extinguishing systems are required throughout the various occupancies of the mill building.

4.2 Structural Analysis

The main elements of the building that were analyzed for this project were the beams and columns of the mill buildings. The maximum allowable moment was found for each structural beam by multiplying the element's allowable bending stress, which is a product of the bending stress and several factors, by the element's section modulus. The element's length and maximum allowable moment were plugged into the basic formula for moment of simply supported beam, shown below. Thus, the maximum allowable load, *w,* was derived for each beam.

$$M = \frac{wL^2}{8}$$

This allowable load was compared to the ultimate load capacity, which was found by summing factored dead, live and self-weight loads. If the allowable load for an individual beam was found to be greater than that beam's load capacity, then the beam was considered to be structurally insufficient. As shown in Table 5, beams on floors W-1-2, W-1-3, W-1-4, and W-2-1 would be in structural failure under the new loading proposed by the architectural plan.

Table 5: Beam moment analysis

Floor No.	Length (ft)	Max Allowable Moment (lb*ft)	Max Allowable Load (lb/ft)	Ultimate Capacity (lb/ft)	Passes?
W-1-1	17.00	68,760.22	1,903.40	1,413.74	Yes
W-1-2	17.00	19,260.22	533.15	1,424.19	No
W-1-3	17.00	19,260.22	533.15	693.74	No
W-1-4	17.00	19,260.22	533.15	1,413.74	No
W-2-1	17.17	24,573.38	667.09	744.34	No
W-3-1	17.00	222,750.00	6,166.09	2,825.48	Yes

In addition, the building's beams were also tested for deflection. Deflection for each beam was solved for by using the model for a simply supported beam,

$$\Delta = \frac{5wL^4}{EI}$$

This allowable value for deflection was compared to the limit, which was taken as the length of the beam divided by 360, and if the allowable deflection exceeded the limit, the beam would be considered to fail. Table 6 shows that in addition to failing under bending conditions, a majority of the beams would fail due to deflection.

Table 6: Beam deflection analysis

Floor No.	Max Allowable Deflection (in)	Deflection Limit (in)	Passes?
W-1-1	2.376	0.567	No
W-1-2	0.781	.5333	No
W-1-3	0.915	0.533	No
W-1-4	2.376	0.567	No
W-2-1	1.019	0.572	No
W-3-1	0.322	0.533	Yes

While it was found that a majority of the building's beams failed under the new proposed loading, the opposite proved to be true for its columns. When tested for axial loading, the only columns in the building that failed were in Building W-1. The columns in Building W-2 were found to be sufficient enough to carry the proposed loading, while those in W-3 were significantly even more so.

Table 7: Column axial load analysis

Floor No.	Material	Length (ft)	Max Allowable Load (kips)	Cumulative Loading (kips)	Passes?
W-1-0	Wood	17.00	75.39	86.03	No
W-1-1	Wood	16.00	43.66	60.81	No
W-1-1	Cast Iron	16.00	65.58	60.81	Yes
W-1-2	Cast Iron	17.00	65.58	37.07	Yes
W-1-3	Cast Iron	16.00	65.58	24.48	Yes
W-2-0	Wood	17.00	35.22	22.69	Yes
W-2-1	Wood	16.00	19.64	12.25	Yes
W-3-0	Cast Iron	17.00	84.30	47.65	Yes
W-3-0	Steel	13.17	377	73.94	Yes
W-3-1	Steel	19.00	301	28.11	Yes

4.3 Design

Similar to the analysis phase, the design phase was broken down into categories of beams and columns. For the design of the wooden beams, the bending stress, shear stress and modulus of elasticity were all taken from tables in the NDS, based on the grade of wood that was chosen.

4.3.1 Upgrade of Structurally Deficient Elements

Block W-1 was the only one out of the three blocks that had structurally deficient beams in need of an upgrade. The upgrade of these beams consisted of

This process was undertaken for floors W-1-2, W-1-3 and W-1-4, where the beams that are currently in place would not sufficiently carry the new expected load.

Table 8: Suggested beam sizes for design areas

Floor Number	Existing Beam Size (in x in)	Suggested Beam Size (in x in)	
		Douglas-fir	Glu-Lam
W-1-2	10 x 14	7.25 x 15	6.75 x 12
W-1-3	8 x 12	7.25 x 11	3.125 x 12
W-1-4	8 x 12	7.25 x 15	6.75 x 12

The Douglas-fir options presented in Table 8 are of Grade No. 1, while the Glu-Lam options are in the 24F-1.8E-V4 stress class. The implementation of these design options, either the Douglas-fir or the Glu-Lam, would successfully bring the beams from a state of failure to one of structural sufficiency. A similar process was followed for columns that were likewise incapable of supporting the new loading.

Floor Number	Existing Column Size (in x in)	Suggested Column Size (in x in)
W-1-0	10 x 10	9.25 x 11.25
W-1-1	8.5 x 8.5	9.25 x 9.25
W-1-5		

Here the design of the columns for W-1-0 and W-1-1 considered two different grades of Douglas-fir, No.1 and Select Structural.

4.3.2 Redesign of W-1-5 Floor Layout

One particular issue that the team found with the architectural plan for the W-1-5 floor was that plan had shown structural rods going through tenant's living spaces. The team deemed that this would interfere with the tenant's level of comfort and decided to develop two new flooring layouts, with which

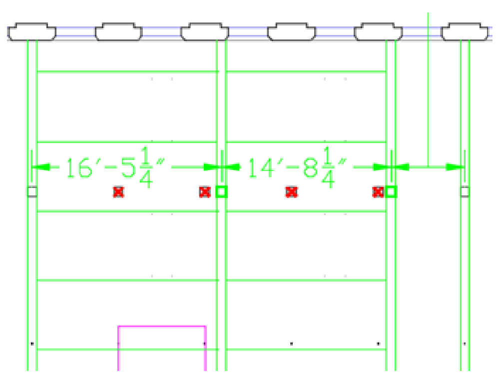

Figure 12: W-1-5 Floor Framing Layout #1

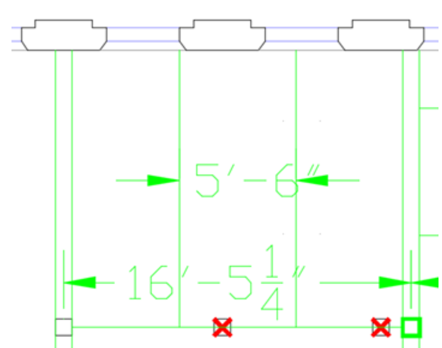

Figure 11: W-1-5 Floor Framing Layout #2

the removal of intrusive rods was included. The first layout option is shown in Figure 11. Here, joists, spaced six feet on center are attached to beams thirteen feet in length with a tributary width of approximately sixteen and a half feet. Figure 12 shows the second framing layout option, where joists spaced five and a half feet on center are attached to beams that are approximately sixteen and a half feet in length.

4.4 Modifications to the Conceptual Plan

Several modifications to the conceptual plan were considered prudent, by the team, to help reduce the cost of the restoration of Gilbertville Mill #4.

The most notable among these modifications is the erection of columns in the place of the load bearing wall that the conceptual plan demolishes. The wall is demolished to make a large open space in the basement of the Picking House, W-2-0, and facilitate a much more open atmosphere for the shops and cafes that would be in that area. The downside to demolishing this wall is that it creates large 30' span with an approximately 12 kip point load in the center of it. Following the load path downward we can see that there is now a tremendous moment that needs to be carried by the beam running between the two remaining columns and that the unevenness of the loading now causes a large eccentricity and moment in the columns themselves. This large load would now need to be carried by much more substantial members, most likely made out of steel.

The alternative plan is to sacrifice some of the openness of the space and install columns along the regular column line where the wall used to be. Structural integrity could be achieved with twenty two 8X8, 10' tall, Douglas Fir-Larch columns. This would reduce the cost from approximately $63,000 to only $5000. This is the most easily quantifiable cost reduction that can be gained from working the conceptual plan around the existing structure through compromise.

4.5 Cost Analysis

In addition to choosing an appropriately sized structural element to withstand the new proposed loading, another limiting agent was the cost of that particular option. These options, shown in Table 9, do not consider any modification of the conceptual plan.

Table 9: Total cost for each design option

Location	Element	Material	Cost
W-1-0	Columns	Douglas Fir	$44,560.80
W-1-1	Columns	Douglas Fir	$41,241.60
W-1-2	Beams	Douglas Fir	$93,003.60
W-1-2	Beams	Glu-Lam	$40,934.00
W-1-3	Beams	Douglas Fir	$54,469.80
W-1-3	Beams	Glu-Lam	$19,245.60
W-1-4	Beams	Douglas Fir	$94,921.20
W-1-4	Beams	Glu-Lam	$41,778.00
W-1-5	Beams	Douglas Fir	$1,095.15
W-1-5	Beams	Douglas Fir	$950.51
W-2-0	Beams	Glu-Lam	$28,116.00
W-2-0	Beams	Steel	$35,099.13
W-2-0	Columns	Steel	$28,314.00

5 Conclusion

This project focused on developing strategies for implementing an architectural renovation plan of Gilbert, George Manufacturing Company Mill No. 4 (Gilbertville Mill No. 4). The mill consists of three individual buildings, which when built, served textile, cotton-picking and dyeing purposes. Now, however, the building is severely under-utilized compared to its early stages, and is used primarily for storage. Using a proposal prepared by a Master's of Architecture candidate, the team began the process of determining if the mill building was structurally capable of being put to a modern use. Of the five project objectives developed by the team, four were met while one was not due to technical difficulties. Despite this

The work done was conducted in five overall steps: a condition assessment, a code review, a structural analysis, structural design and a cost analysis. Streamlining the work down into these five phases allowed the team to produce multiple conclusions for design areas with different criteria. The design work consisted of three categories: structural upgrades, alternative framing layouts and modifications to the architectural plan.

The project produced by the team should be used as an initial stepping stone in moving the project forward. While the team tried to be as comprehensive as possible, there were several factors unaccounted for in the structural renovations that would definitely need to be addressed in a formal engineering project to renovate the mill. These recommendations are explained fully in Section 6.

6 Recommendations & Areas for Further Investigation

In this chapter, a summarized list of recommendations is provided based off of the design work that was done. Additionally, this chapter explores areas that were out of the scope of this project, but that could help for future progress.

6.1 Recommendations

This section is intended to give a brief overview of the final findings produced by the team, as well as to provide suggestions for possibly decreasing the estimated cost of the project.

6.1.1 Cost Efficient Options

After determining the cost of all options, the team narrowed those options down to the ones that were most cost efficient, as shown in Table 10.

Table 10: Cost-efficient options for design areas

Location	Element	Material	Cost
W-1-0	Columns	Douglas Fir	$44,560.80
W-1-1	Columns	Douglas Fir	$41,241.60
W-1-2	Beams	Douglas Fir	$93,003.60
W-1-2	Beams	Glu-Lam	$40,934.00
W-1-3	Beams	Glu-Lam	$19,245.60
W-1-4	Beams	Glu-Lam	$41,778.00
W-1-5	Beams	Douglas Fir	$950.51
W-2-0	Beams	Glu-Lam	$28,116.00
W-2-0	Columns	Steel	$28,314.00

6.1.2. Alternative to Retrofitting W-1-5

Providing a design for the retrofit of W-1-5 proved to be an interesting challenge. But the design may not necessarily be the most cost effective. The team determined that rather than remodel the building to fit the architectural plan, it would be much more efficient, both structurally and financially, to better suit the architectural plan to the current set-up of the building. The floor of W-1-5 would still need to be renovated, but if the proposal were to incorporate a different use for that floor that required less of a load capacity, there would surely be a decrease in expected finances.

6.2 Areas for Further Investigation

Foundation Evaluation

A much more thorough analysis would have been completed had the team had resources necessary to conduct an analysis of the building's foundation. The foundation is an integral part of the building system, as it is the component that upholds the actual structure. It could be subjected to bearing and settlement failure over time, or even sooner if the allowable bearing pressure were to exceed the bearing capacity due to the proposed induced loading. The design or evaluation of a foundation would first and foremost require an appropriate level of knowledge of the soil properties that the site is located on. An estimate of what soil layers lay below the surface could have been made using free geological services offered online, such as a Web Soil Survey. But for a structural plan meant for construction, the soil data would have to be backed up by percolation tests and lab testing of samples.

Wood Inspection

The designs developed in the project were based off of the initial assumption that the quality of wood in the building was as poor as possible. This assumption was made as a safeguard, so as to prevent the possibility of the team overlooking a potential design area. If Mr. Salem were to have a professional wood inspection done on the structural elements in the building, he would be able to determine what quality of wood was being used. Doing so, could potentially negate the assumption made by the team and could even uncover that a higher quality of wood than what was initially assumed was already in place.

7 References

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8 Appendices

Appendix A: Definitions

Addition – an extension or increase in floor area, number of stories, or height of a building or structure

Alteration – any construction or renovation to an existing structure other than a repair or addition. Alterations are classified as Level 1, Level 2 and Level 3

Automatic sprinkler system – an automatic sprinkler system, for fire protection purposes, is an integrated system of underground and overhead piping designed in accordance with fire protection engineering standards. The system includes a suitable water supply. The portion of the system above the ground is a network of specially sized or hydraulically designed piping installed in a structure or area, generally overhead, and to which automatic sprinklers are connected in a systematic pattern. The system is usually activated by heat from a fire and discharges water over the fire area.

Change of occupancy – a change in the purpose or level of activity within a building that involves a change in application of the requirements of this code

Code official – the officer or other designated authority charged with the administration and enforcement of this code

Dangerous – any building, structure, or portion thereof that meets any of the conditions described below shall be deemed dangerous

1. The building or structure has collapsed, has partially collapsed, has moved off its foundation, or lacks the necessary support of the ground
2. There exists a significant risk of collapse, detachment or dislodgement of any portion, member, appurtenance or ornamentation of the building or structure under service loads

Emergency voice/alarm communication – dedicated manual or automatic facilities for originating and distributing voice instructions, as well as alert and evacuation signals pertaining to a fire emergency, to the occupants of a building

Existing building – a building erected prior to the date of adoption of the appropriate code, or one for which a legal building permit has been issued

Facility – all of any portion of buildings, structures, site improvements, elements and pedestrian or vehicular routes located on a site

Factored load – the product of a nominal load and a load factor

Fire area – the aggregate floor area enclosed and bounded by fire walls, fire barriers, exterior walls or horizontal assemblies of a building. Areas of the building not provided with surrounding walls shall be included in the fire area if such areas are included within the horizontal projection of the roof or floor next above

Fire partition* – a vertical assembly of materials designed to restrict the spread of fire in which openings are protected. Have a fire resistance from 1h-2h.

Fire resistance – that property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gases or flames under conditions of use

Fire-resistance rating – the period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by the tests, or the methods based on tests, prescribed in Section 703

Fire wall* – a fire-resistance-rated wall having protected openings, which restricts the spread of fire and extends continuously from the foundation to or through the roof, with sufficient stability under fire conditions to allow collapse of construction on either side without collapse of the wall. A standard fire wall has a fire resistance rating of at least 4h.

Flood hazard area – the greater of the following two areas:

1. The area within a flood plain subject to a 1% or greater chance of flooding in any year
2. The area designated as a flood hazard area on a community's flood hazard map, or otherwise legally designated

Flood Insurance Rate Map (FIRM) – an official map of a community on which the Federal Emergency Management Agency (FEMA) has delineated both the areas of special flood hazard and the risk premium zones applicable to the community

Historic building – any building or structure that is listed in the State or National Register of Historic Places; designated as a historic property under local or state designation law or survey; certified as a contributing resource within a National Register listed or locally designated historic district; or with an opinion or certification that the property is eligible to be listed on the National or State Register of Historic Places either individually or as a contributing building to a historic district by the State Historic Preservation Officer or the Keeper of the National Register of Historic Places

Load and resistance factor design – a method of proportioning structural members and their connections using load and resistance factors such that no applicable limit state is reached when the structure is subjected to appropriate load combinations. The term "LRFD" is used in the design of steel and wood structures.

Load bearing element – any column, girder, beam, joist, truss, rafter, wall, floor or roof sheathing that supports any vertical load in addition to its own weight or any lateral load

Load effect – forces and deformations produced in structural members by the applied loads

Load factor – a factor that accounts for deviations of the actual load from the nominal load, for uncertainties in the analysis that transforms the load into a load effect, and for the probability that more than one extreme load will occur simultaneously

Means of egress – a continuous and unobstructed path of vertical and horizontal travel from any occupied portion of a building or structure to a public way. A means of egress consists of three separate and distinct parts: the exit access, the exit and the exit discharge.

Nominal loads – the magnitudes of the loads specified in Chapter 16 [of the *IBC*]

Primary function – a primary function is a major activity for which the facility is intended. Areas that contains a primary function include, but are not limited to, the customer services lobby of a bank, the dining area of a cafeteria, the meeting rooms in a conference center, as well as offices and other work areas in which the activities of the public accommodation or other private entity using the facility are carried out. Mechanical rooms, boiler rooms, supply storage rooms, employee lounges or locker rooms, janitorial closets, entrances, corridors and restrooms are not areas containing a primary function.

Public way – a street, alley, or other parcel of land open to the outside air leading to a street, that has been deeded, dedicated or otherwise permanently appropriated to the public for public use and which has a clear width and height of not less than 10 feet

Rehabilitation – any work, as described by the categories of work defined herein, undertaken in an existing building

Rehabilitation, Seismic – work conducted to improve the seismic lateral force resistance of an existing building

Repair – the restoration to good or sound condition of any part of an existing building for the purpose of its maintenance

Seismic loading – the forces prescribed herein, related to the response of the structure to earthquake motions, to be used in the analysis and design of the structure and its components

Substantial damage – for the purpose of determining compliance with the flood provisions of this code, damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damaged condition would equal or exceed 50% of the market value of the structure before the damage occurred

Substantial improvement – for the purpose of determining compliance with the flood provisions of this code, any repair, alteration, addition, or improvement of a building or structure, the cost of which equals or exceeds 50% of the market value of the structure, before the improvement or repair is started. If the structure has sustained substantial damage, any repairs are considered substantial improvement regardless of the actual repair work performed. The term does not include either

1. Any project for improvement of a building required to correct existing health, sanitary, or safety code violations identified by the code official and that is the minimum necessary to ensure safe living conditions; or

2. Any alteration of a historic structure, provided that the alteration will not preclude the structure's continued designation as a historic structure

Substantial structural damage – a condition where:

1. In any story, the vertical elements of the lateral force-resisting system have suffered damage such that the lateral load-carrying capacity of the structure in any horizontal direction has been reduced by more than 33% from its pre-damage condition; or

2. The capacity of any vertical gravity load-carrying component, or any group of such components, that supports more than 30% of the total area of the structure's floor(s) and roof(s) has been

reduced more than 20% from its pre-damage condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75% of that required by this code for new buildings of similar structure, purpose and location

Technically infeasible – an alteration of a facility that has little likelihood of being accomplished because the existing structural conditions require the removal or alteration of a load-bearing member that is an essential part of the structural frame, or because other existing physical or site constraints prohibit modification or addition of elements, spaces or features which are in full and strict compliance with the minimum requirements for new construction and which are necessary to provide accessibility

Unsafe – buildings, structures or equipment that are unsanitary, or that are deficient due to inadequate means of egress facilities, inadequate light and ventilation, or that constitute a fire hazard, or in which the structure or individual structural members meet the definition of "Dangerous", or that are otherwise dangerous to human life or the public welfare, or that involve illegal or improper occupancy or inadequate maintenance shall be deemed unsafe. A vacant structure that is not secured against entry shall be deemed unsafe

Wall, Load-bearing – any wall meeting the either of the following classifications

1. Any metal or wood stud wall that supports more than 100 pounds per linear foot (1459 N/m) of vertical load in addition to its own weight
2. Any masonry or concrete wall that supports more than 200 pounds per linear foot (2919 N/m) of vertical load in addition to its own weight

Wall, Non load-bearing – any wall that is not a load-bearing wall

Work area – that portion or portions of a building consisting of all reconfigured spaces as indicated on the construction documents. Work area excludes other portions of the building where incidental work entailed by the intended work must be performed and portions of the building where work not initially intended by the owner is specifically required by this code

Appendix B: Conceptual Plan Booklet

PROPOSED GILBERTVILLE MILL DEVELOPMENT

Owner:
MELAS, Inc.
The Salem Family

Designer:
Shehla Hussain
Master of Architecture Candidate 2010
University of Massachusetts, Amherst

Instructor:
Michael Di Pasquale
UMass Extension Educator
Citizen Planner Training Collaborative

July 15, 2009

CONTENTS

ADDENDUM


MASS MoCA, Massachusetts, USA

Outfitted with state-of-the-art equipment, Sprague was a major research and development center, conducting studies on the nature of electricity and semi-conducting materials.
In 1986, just a year after Sprague's closing, the business and political leaders of North Adams were seeking ways to creatively re-use the vast Sprague complex.

Originally conceived as an institution for the display of contemporary visual arts, MASS MoCA evolved, under Joseph C. Thompson's leadership, into a center that would both present and catalyze the creation of works that chart new creative territory.


Custard Factory, Birmingham, England

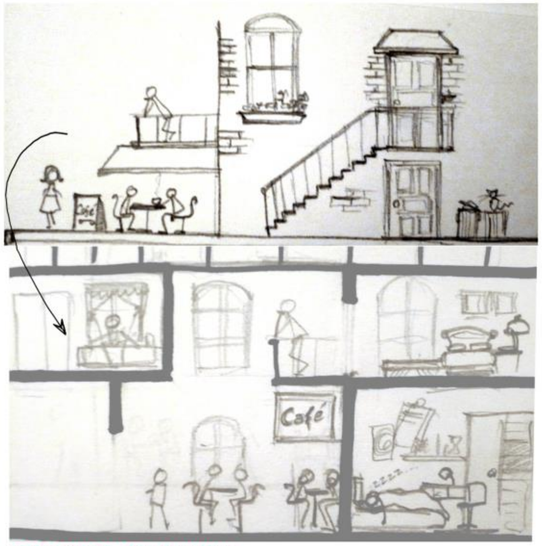
When the original factory was converted to cheap start-up units for creative types, it became a magnet for creative industries, quickly reaching critical mass. It's now a self sustaining community of web designers, graphic artists, promoters, publishers and all shades of makers, movers and shakers.

The award-winning first phase is home to a dynamic bohemian community of 500 artists and small creative enterprises. The affordable studio workshops are complemented by a theatre café, antique shops, meeting rooms, dance studios, holistic therapy rooms, art galleries, bars and nightclubs.


Dia:Beacon, New York, USA

The museum, which opened in 2003, is situated on the banks of the Hudson River in Beacon, New York. Dia:Beacon occupies a former Nabisco box-printing facility that was renovated by Dia with artist Robert Irwin and architect OpenOffice. Along with Dia's permanent collection, Dia:Beacon also presents temporary exhibitions, as well as public programs designed to complement the collection and exhibitions, including monthly Gallery Talks, Merce Cunningham Dance Company Events, Community Free Days for neighboring counties, and an education program that serves area students at all levels.

PRECEDENTS



CONCEPTS

CONCEPT SUMMARY

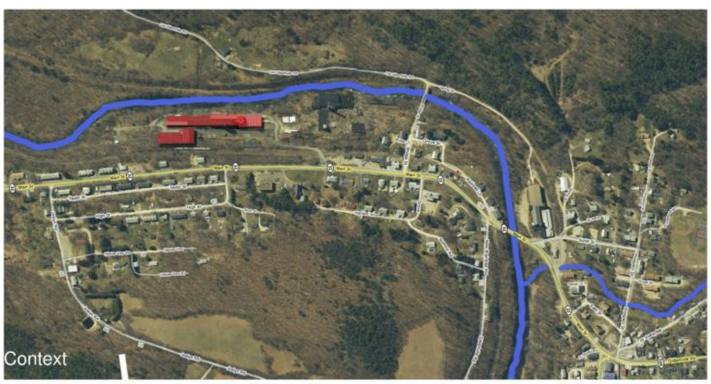
To recreate an environment of typical outdoor urban community life on the inside of the existing built structure.

APPROACH

To develop the indoor spaces to be lively and engage the user, the proposal for the existt ing mill building, in all its industrial appeal, has been inspired from outdoor 'built' environn ments (namely man-made developments) adapted within the structure.

The entire planning is dominated by the concept of 'overlapping' the programs, while still retaining privacy where needed. This has been achieved by playing with lines of vision/observation. Example: Residential balconies overlooking commercial spaces below; people circulating through public galleries viewing artists work in their studios

5



Location
268 Main St.
Gilbertville, MA 01031

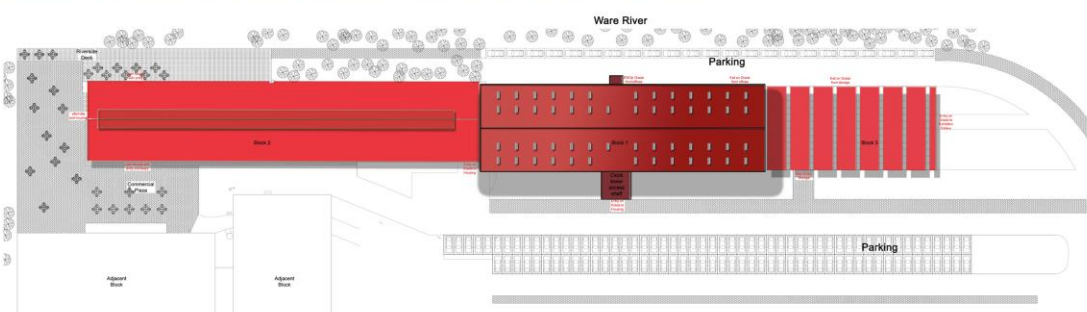
Existing conditions
Consists of 2 buildings (east and west)
West block: Comprised of 3 parts, -
Block 1- 4 floors+basement+attic
Block 2- 1 floor+basement
Block 3- 1 floor+basement
East Block: Comprised of 2 parts- both consist of 3 floors

Current Use
Storage/Manufacturing/Office

Proposal
To redevelop the mill into a Creative Arts Community.

Client:
MELAS Inc.
The Salem Family
Design and drawings:
University of Massachusetts, Amherst
Architecture + Design

Proposed Gilbertville Mill Development
Context + Site Plan

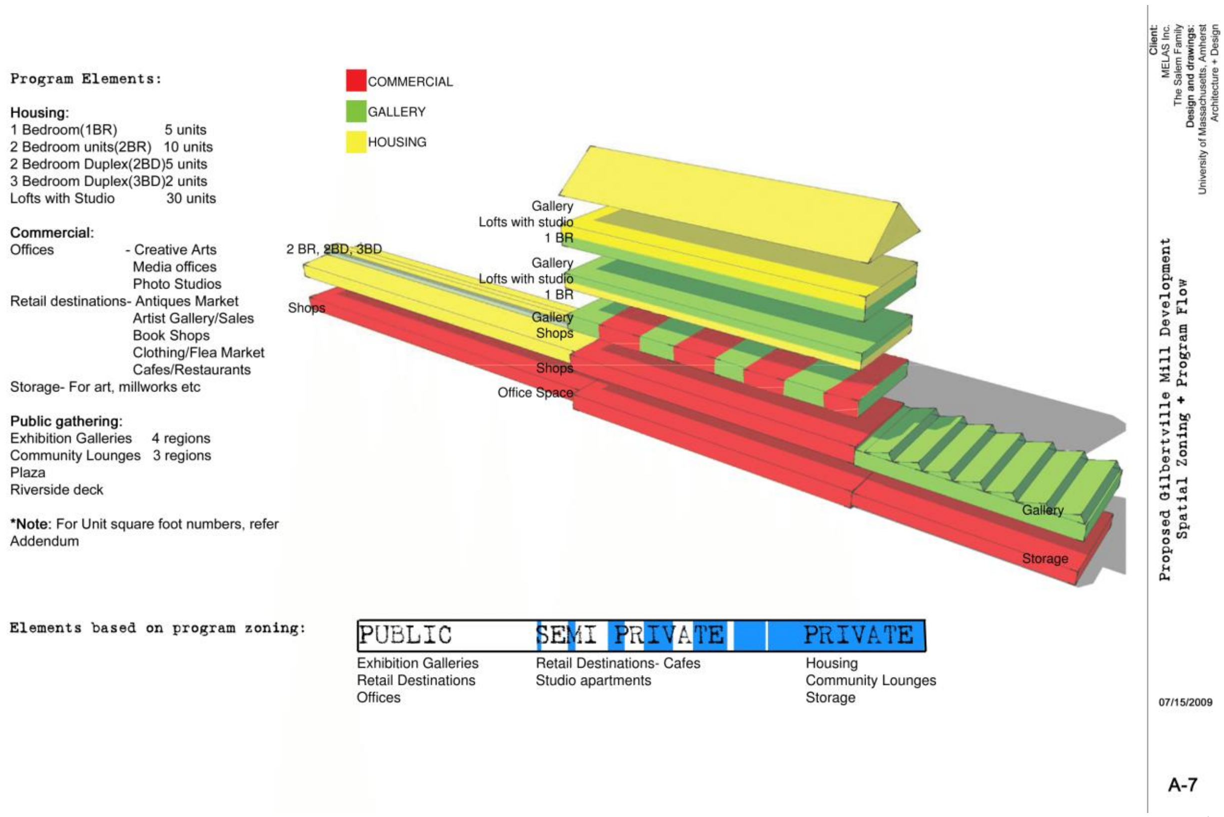


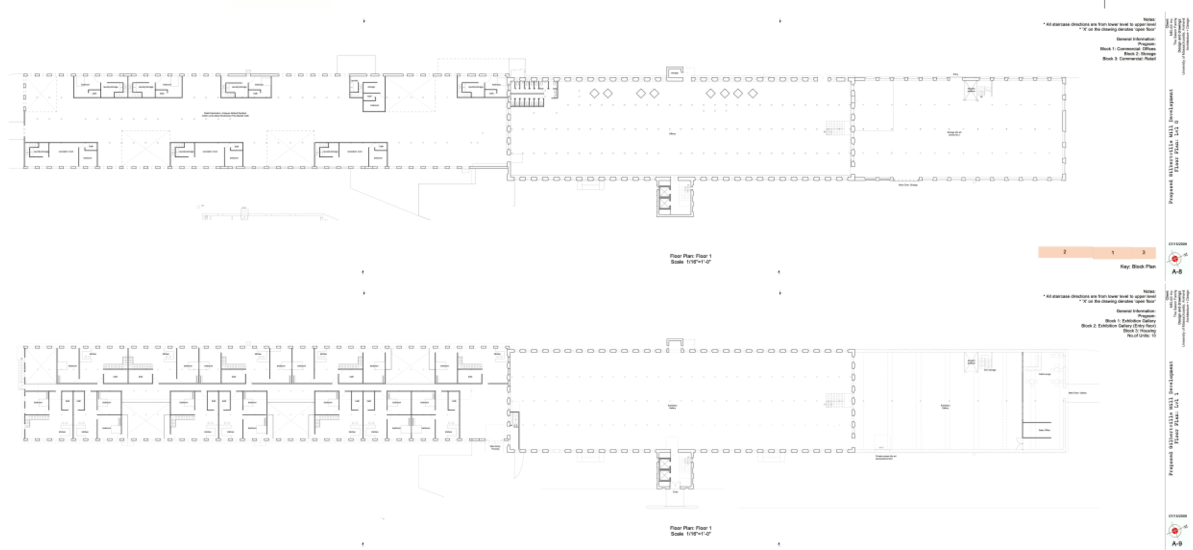
07/15/2009

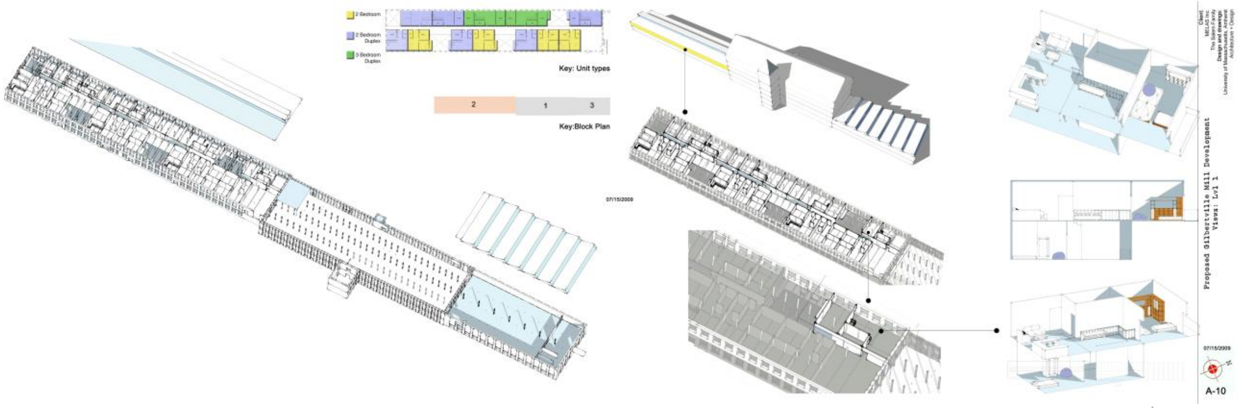
Entry from Main Road

Proposed: Site Plan

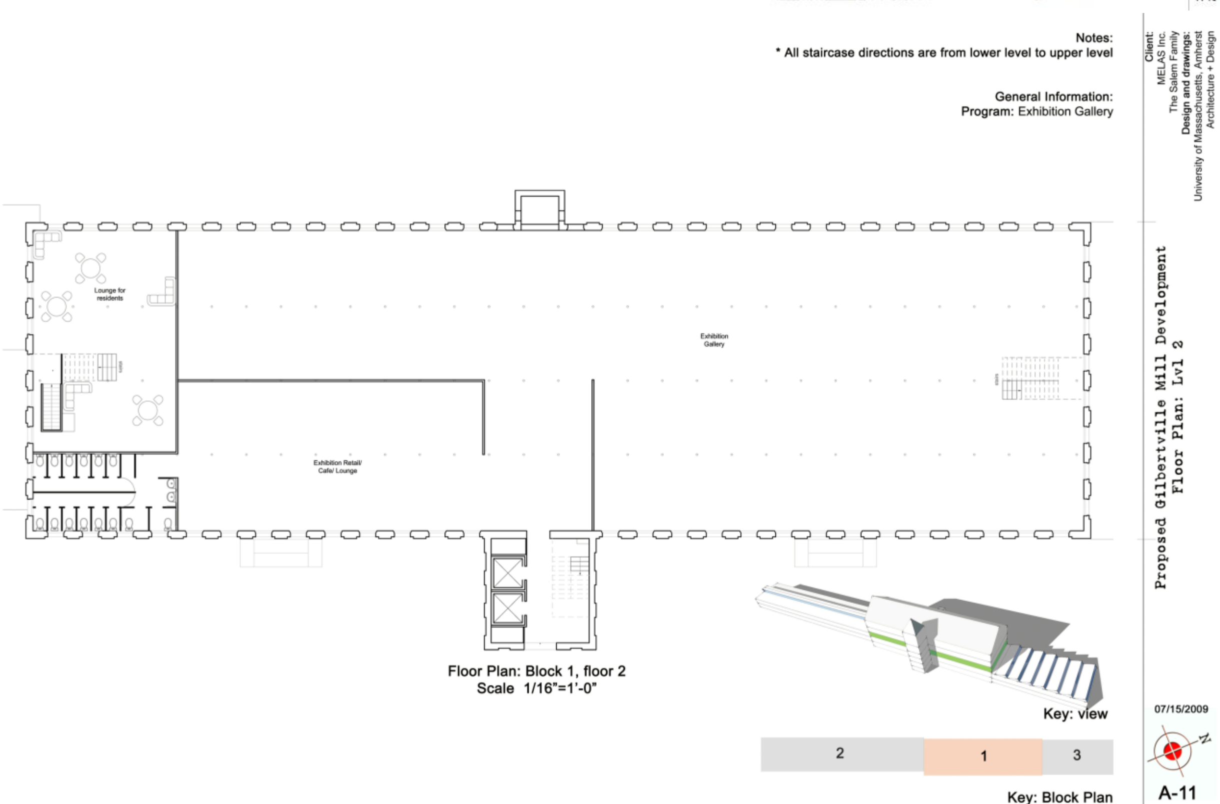
A- 6


Program Elements:
Housing:
1 Bedroom(1BR) 5 units
2 Bedroom units(2BR) 10 units
2 Bedroom Duplex(2BD)5 units
3 Bedroom Duplex(3BD)2 units
Lofts with Studio 30 units
Commercial:
Offices - Creative Arts
Media offices
Photo Studios
Retail destinations- Antiques Market
Artist Gallery/Sales
Book Shops
Clothing/Flea Market
Cafes/Restaurants
Storage- For art, millworks etc
Public gathering:
Exhibition Galleries 4 regions
Community Lounges 3 regions
Plaza
Riverside deck
*Note: For Unit square foot numbers, refer Addendum
COMMERCIAL
GALLERY
HOUSING
Gallery
Lofts with studio
1 BR
2 BR, 2BD, 3BD
Gallery
Lofts with studio
1 BR
Shops
Gallery
Shops
Shops
Office Space
Gallery
Storage
Elements based on program zoning:
PUBLIC
SEMI PRIVATE
PRIVATE
Exhibition Galleries
Retail Destinations
Offices
Retail Destinations- Cafes
Studio apartments
Housing
Community Lounges
Storage
Client:
MELAS Inc.
The Salem Family
Design and drawings:
University of Massachusetts, Amherst
Architecture + Design
Proposed Gilbertville Mill Development
Spatial Zoning + Program Flow
07/15/2009
A-7

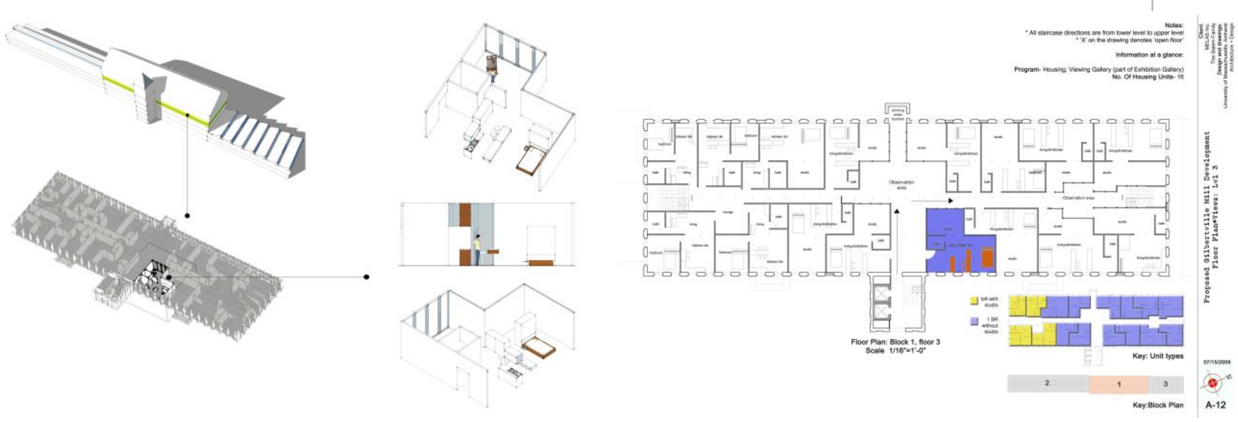




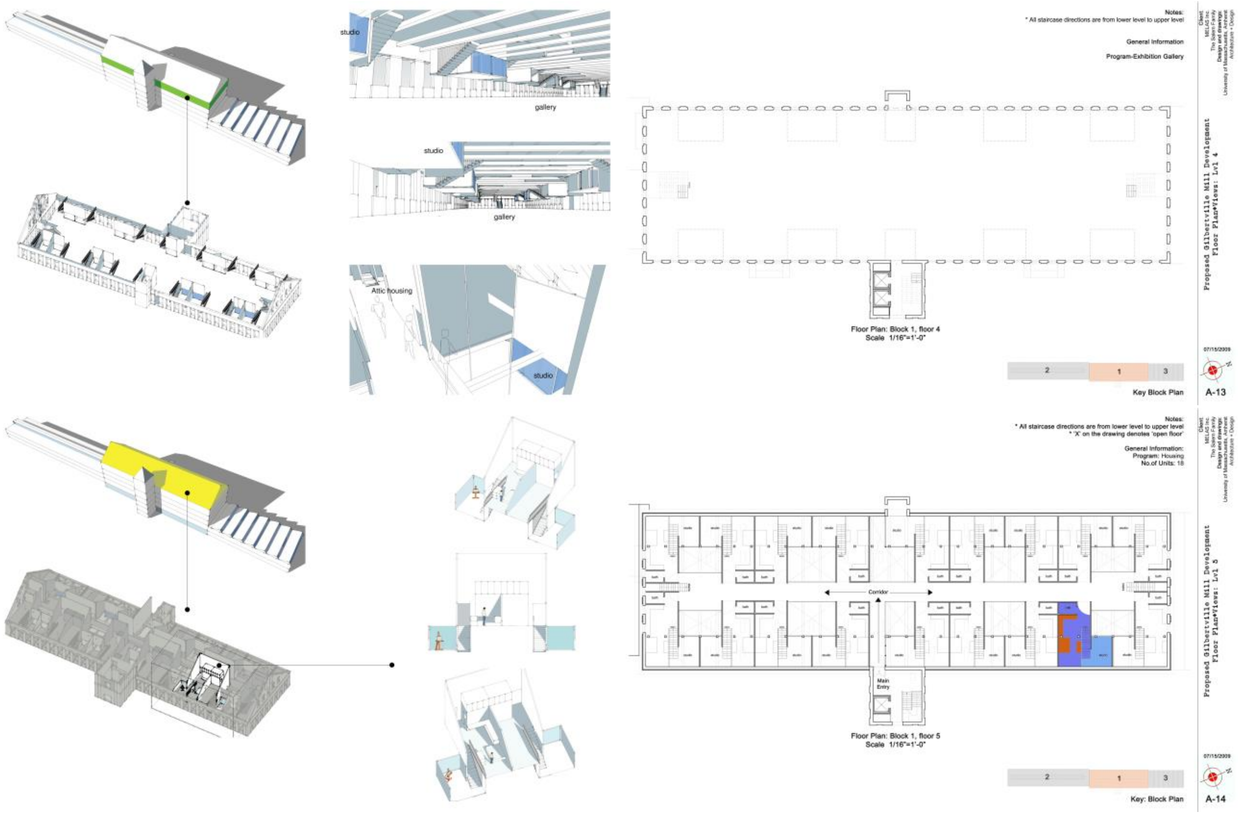
Key: Unit types
Key:Block Plan
07/15/2009
Proposed Gilbertville Mill Development
Views: Lvl 1
07/15/2009
A-10



Notes:
* All staircase directions are from lower level to upper level
General Information:
Program: Exhibition Gallery
Client:
MELAS Inc.
The Salem Family
Design and drawings:
University of Massachusetts, Amherst
Architecture + Design
Lounge for residents
Exhibition Gallery
Exhibition Retail/ Cafe/ Lounge
Proposed Gilbertville Mill Development
Floor Plan: Lvl 2
Floor Plan: Block 1, floor 2
Scale 1/16"=1'-0"
Key: view
07/15/2009
2
1
3
Key: Block Plan
A-11



Notes:
* All staircase directions are from lower level to upper level
* 'X' on the drawing denotes 'open floor'
Information at a glance:
Program- Housing; Viewing Gallery (part of Exhibition Gallery)
No. Of Housing Units- 16
Proposed Gilbertville Mill Development
Floor Plan+Views: Lvl 3
Floor Plan: Block 1, floor 3
Scale 1/16"=1'-0"
Key: Unit types
07/15/2009
2
1
3
Key:Block Plan
A-12


studio
gallery
studio
gallery
Attic housing
studio
Notes:
* All staircase directions are from lower level to upper level
General Information
Program-Exhibition Gallery
Floor Plan: Block 1, floor 4
Scale 1/16"=1'-0"
2
1
3
Key Block Plan
07/15/2009
A-13
Proposed Gilbertville Mill Development
Floor Plan+Views: Lvl 4
Notes:
* All staircase directions are from lower level to upper level
* 'X' on the drawing denotes 'open floor'
General Information:
Program: Housing
No.of Units: 18
Corridor
Main Entry
Floor Plan: Block 1, floor 5
Scale 1/16"=1'-0"
2
1
3
Key: Block Plan
07/15/2009
A-14
Proposed Gilbertville Mill Development
Floor Plan+Views: Lvl 5

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PHASING

Appendix C: IBC 2012 Occupancy and Load Cases

TABLE 1607.1
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
1. Apartments (see residential)	—	—
2. Access floor systems Office use Computer use	 50 100	 2,000 2,000
3. Armories and drill rooms	150[m]	—
4. Assembly areas Fixed seats (fastened to floor) Follow spot, projections and control rooms Lobbies Movable seats Stage floors Platforms (assembly) Other assembly areas	 60[m] 50 100[m] 100[m] 150[m] 100[m] 100[m]	—
5. Balconies and decks[h]	Same as occupancy served	—
6. Catwalks	40	300
7. Cornices	60	—
8. Corridors First floor Other floors	 100 Same as occupancy served except as indicated	—
9. Dining rooms and restaurants	100[m]	—
10. Dwellings (see residential)	—	—
11. Elevator machine room grating (on area of 2 inches by 2 inches)	—	300
12. Finish light floor plate construction (on area of 1 inch by 1 inch)	—	200
13. Fire escapes On single-family dwellings only	100 40	—
14. Garages (passenger vehicles only) Trucks and buses	40[m] See Section 1607.7	Note a
15. Handrails, guards and grab bars	See Section 1607.8	
16. Helipads	See Section 1607.6	
17. Hospitals Corridors above first floor Operating rooms, laboratories Patient rooms	 80 60 40	 1,000 1,000 1,000
18. Hotels (see residential)	—	—
19. Libraries Corridors above first floor Reading rooms Stack rooms	 80 60 150[b, m]	 1,000 1,000 1,000
20. Manufacturing Heavy Light	 250[m] 125[m]	 3,000 2,000
21. Marquees	75	—
22. Office buildings Corridors above first floor File and computer rooms shall be designed for heavier loads based on anticipated occupancy Lobbies and first-floor corridors Offices	 80 — 100 50	 2,000 — 2,000 2,000

(continued)

TABLE 1607.1—continued
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
23. Penal institutions		
Cell blocks	40	—
Corridors	100	
24. Recreational uses:		
Bowling alleys, poolrooms and similar uses	75[m]	
Dance halls and ballrooms	100[m]	
Gymnasiums	100[m]	—
Reviewing stands, grandstands and bleachers	100[c, m]	
Stadiums and arenas with fixed seats (fastened to floor)	60[c, m]	
25. Residential		
One- and two-family dwellings		
Uninhabitable attics without storage[i]	10	
Uninhabitable attics with storage [i, j, k]	20	
Habitable attics and sleeping areas[k]	30	
All other areas	40	—
Hotels and multifamily dwellings		
Private rooms and corridors serving them	40	
Public rooms[m] and corridors serving them	100	
26. Roofs		
All roof surfaces subject to maintenance workers		300
Awnings and canopies:		
Fabric construction supported by a skeleton structure	5 nonreducible	
All other construction	20	
Ordinary flat, pitched, and curved roofs (that are not occupiable)	20	
Where primary roof members are exposed to a work floor, at single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs:		
Over manufacturing, storage warehouses, and repair garages		2,000
All other primary roof members		300
Occupiable roofs:		
Roof gardens	100	
Assembly areas	100[m]	
All other similar areas	Note 1	Note 1
27. Schools		
Classrooms	40	1,000
Corridors above first floor	80	1,000
First-floor corridors	100	1,000
28. Scuttles, skylight ribs and accessible ceilings	—	200
29. Sidewalks, vehicular drive ways and yards, subject to trucking	250[d, m]	8,000[e]

(continued)

TABLE 1607.1—continued
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
30. Stairs and exits One- and two-family dwellings All other	 40 100	 300[f] 300[f]
31. Storage warehouses (shall be designed for heavier loads if required for anticipated storage) Heavy Light	 250[m] 125[m]	—
32. Stores Retail First floor Upper floors Wholesale, all floors	 100 75 125[m]	 1,000 1,000 1,000
33. Vehicle barriers	See Section 1607.8.3	
34. Walkways and elevated platforms (other than exitways)	60	—
35. Yards and terraces, pedestrians	100[m]	—

For SI: 1 inch = 25.4 mm, 1 square inch = 645.16 mm^2,
1 square foot = 0.0929 m^2,
1 pound per square foot = 0.0479 kN/m^2, 1 pound = 0.004448 kN,
1 pound per cubic foot = 16 kg/m^3.

a. Floors in garages or portions of buildings used for the storage of motor vehicles shall be designed for the uniformly distributed live loads of Table 1607.1 or the following concentrated loads: (1) for garages restricted to passenger vehicles accommodating not more than nine passengers, 3,000 pounds acting on an area of 4.5 inches by 4.5 inches; (2) for mechanical parking structures without slab or deck that are used for storing passenger vehicles only, 2,250 pounds per wheel.

b. The loading applies to stack room floors that support nonmobile, double-faced library book stacks, subject to the following limitations:
1. The nominal bookstack unit height shall not exceed 90 inches;
2. The nominal shelf depth shall not exceed 12 inches for each face; and
3. Parallel rows of double-faced book stacks shall be separated by aisles not less than 36 inches wide.

c. Design in accordance with ICC 300.

d. Other uniform loads in accordance with an approved method containing provisions for truck loadings shall also be considered where appropriate.

e. The concentrated wheel load shall be applied on an area of 4.5 inches by 4.5 inches.

f. The minimum concentrated load on stair treads shall be applied on an area of 2 inches by 2 inches. This load need not be assumed to act concurrently with the uniform load.

g. Where snow loads occur that are in excess of the design conditions, the structure shall be designed to support the loads due to the increased loads caused by drift buildup or a greater snow design determined by the building official (see Section 1608).

h. See Section 1604.8.3 for decks attached to exterior walls.

i. Uninhabitable attics without storage are those where the maximum clear height between the joists and rafters is less than 42 inches, or where there are not two or more adjacent trusses with web configurations capable of accommodating an assumed rectangle 42 inches in height by 24 inches in width, or greater, within the plane of the trusses. This live load need not be assumed to act concurrently with any other live load requirements.

(continued)

TABLE 1607.1—continued
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o, AND MINIMUM CONCENTRATED LIVE LOADS[g]

j. Uninhabitable attics with storage are those where the maximum clear height between the joists and rafters is 42 inches or greater, or where there are two or more adjacent trusses with web configurations capable of accommodating an assumed rectangle 42 inches in height by 24 inches in width, or greater, within the plane of the trusses.

   The live load need only be applied to those portions of the joists or truss bottom chords where both of the following conditions are met:

   i. The attic area is accessible from an opening not less than 20 inches in width by 30 inches in length that is located where the clear height in the attic is a minimum of 30 inches; and

   ii. The slopes of the joists or truss bottom chords are no greater than two units vertical in 12 units horizontal.

   The remaining portions of the joists or truss bottom chords shall be designed for a uniformly distributed concurrent live load of not less than 10 lb./ft^2.

k. Attic spaces served by stairways other than the pull-down type shall be designed to support the minimum live load specified for habitable attics and sleeping rooms.

l. Areas of occupiable roofs, other than roof gardens and assembly areas, shall be designed for appropriate loads as approved by the building official. Unoccupied landscaped areas of roofs shall be designed in accordance with Section 1607.12.3.

m. Live load reduction is not permitted unless specific exceptions of Section 1607.10 apply.