# Architectural Design and Value Engineering: A Cross-Disciplinary Study

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## BACKGROUND

Before a new design approach or construction technique will be accepted, its potential value to the industry must be evaluated. If an idea does not possess inherent cost or time savings, it has a low probability of wide-spread industry use. Thus, the first step in the development of a new approach must be a systematic value analysis that compares the new approach to the status quo and quantifies the potential savings. Without the promise of increased value, further development will be slow and remain in the realm of theory rather than practical application. Such was the approach that guided an interdisciplinary team of researchers at Texas Tech University. The team consisted of an architect and engineer, assisted by upper level undergraduate students. This paper will describe important aspects of the interdisciplinary process and results of the research. The central challenge was to combine the architectural and engineering qualities of two common materials in a manner that provided a cost effective product and was innovative in both form and structure. The introduction of value engineering concepts at the beginning of the design process was an additional challenge. This approach required each team member to "introduce" himself to the other member to help establish agreement about areas of individual and shared expertise and responsibility. As a result, some misconceptions about architects and engineers were uncovered and addressed.

The combination of pre-engineered steel structures and single wythe brick walls is the relationship of two dissimilar systems and materials. On one hand, steel is a highly engineered substance capable of being manufactured and installed to extremely precise tolerances. Used in pre-engineered steel structures, it is further refined to optimize the structural capacity of the material to minimize cost. These factors have led to the development of metal building systems (hereafter referred to as MBS). Brick, on the other hand, is the embodiment of imprecision. Its strength is a function of the type clay and the manufacturing process [Curtin 1982, 24-27, Huntington 1981, 162-165]. Even when manufactured under the most controlled conditions, brick is still a relatively fragile material. Its installation is also an imprecise process. The final dimensions of a brick structure greatly depend on the ability of the masons to judge the accuracy of both the width and depth of the mortar bed. Tolerances of plus or minus one eighth to one half inch is the standard of the industry [Huntington 1982, 162-165, Randall 1976, 9-11, Plummer 1962, 340-355]. In spite of this apparent dichotomy, the idea of bringing these two materials together seemed to offer a challenge to formal design thought and possible savings in both design and construction costs. The area of industry which would be most ripe for this application is light commercial development. Retail facilities are single story structures generally built of a combination of steel frames and concrete block walls covered with a brick veneer. On the surface, replacing the structural steel frame with MBS appears to offer immediate savings of both design and material costs. Additional savings could be found by changing the function of the brick from an exterior architectural finish to a structural component. This would allow for the deletion of the concrete masonry units as structural support. Thus, the promise of savings existed, and a systematic economic analysis needed to be undertaken to quantify them.

## VALUE ENGINEERING

To analyze the potential savings attributable to this new design approach, we turned to Value Engineering. The term Value Engineering has many different definitions. The definition used by the American Association of Cost Engineers is:

> "Value Engineering — a practice function targeted at the design itself, which has as its objective the development of a design of a facility or item that will yield the least life-cycle costs or provide greatest value while *satisfying all performance and other criteria* (emphasis added by authors) established for it. [AACE 1990, 98-99].

Edward R. Fisk offers this definition:

"Value engineering is simply a *systematic evaluation* (emphasis added by authors) of project design to obtain the most value for every dollar of cost." [Fisk 1992, 373]

Finally, *Means Illustrated Construction Dictionary* provides this simple definition:

"A science that studies the relative value of *various materials and construction techniques* (emphasis added by authors)." [Means 1991, 469]

Conducting this study involves defining the intrinsic function of the item under analysis. The goal is to provide the same *function* at a lower cost. One means to accomplish this is to use the Functional Analysis System Technique (hereafter referred to as FAST) [Macedo 1978, 231-237]. FAST allows the definition and charting of the salient functional elements of the item in question. In this analysis, the item under study was the structure of a single story, light commercial building. Current construction techniques use a structural steel frame with a concrete block wall to carry the design loads. The wall is then covered with a brick veneer. The brick acts as a first line moisture barrier and as an exterior finish. Thus two primary functions are in question: structural strength and finished appearance.

## FAST ANALYSIS

Figure 1 shows the FAST diagrams for the structural steel, the concrete block and the brick veneer that make up the current design approach for light commercial buildings. Comparing the three diagrams, it is interesting to note that all three materials have compressive strength yet only the steel has this as a critical function. Thus a redundant material capability exists. The current design incorporates three different materials that can all provide the same function

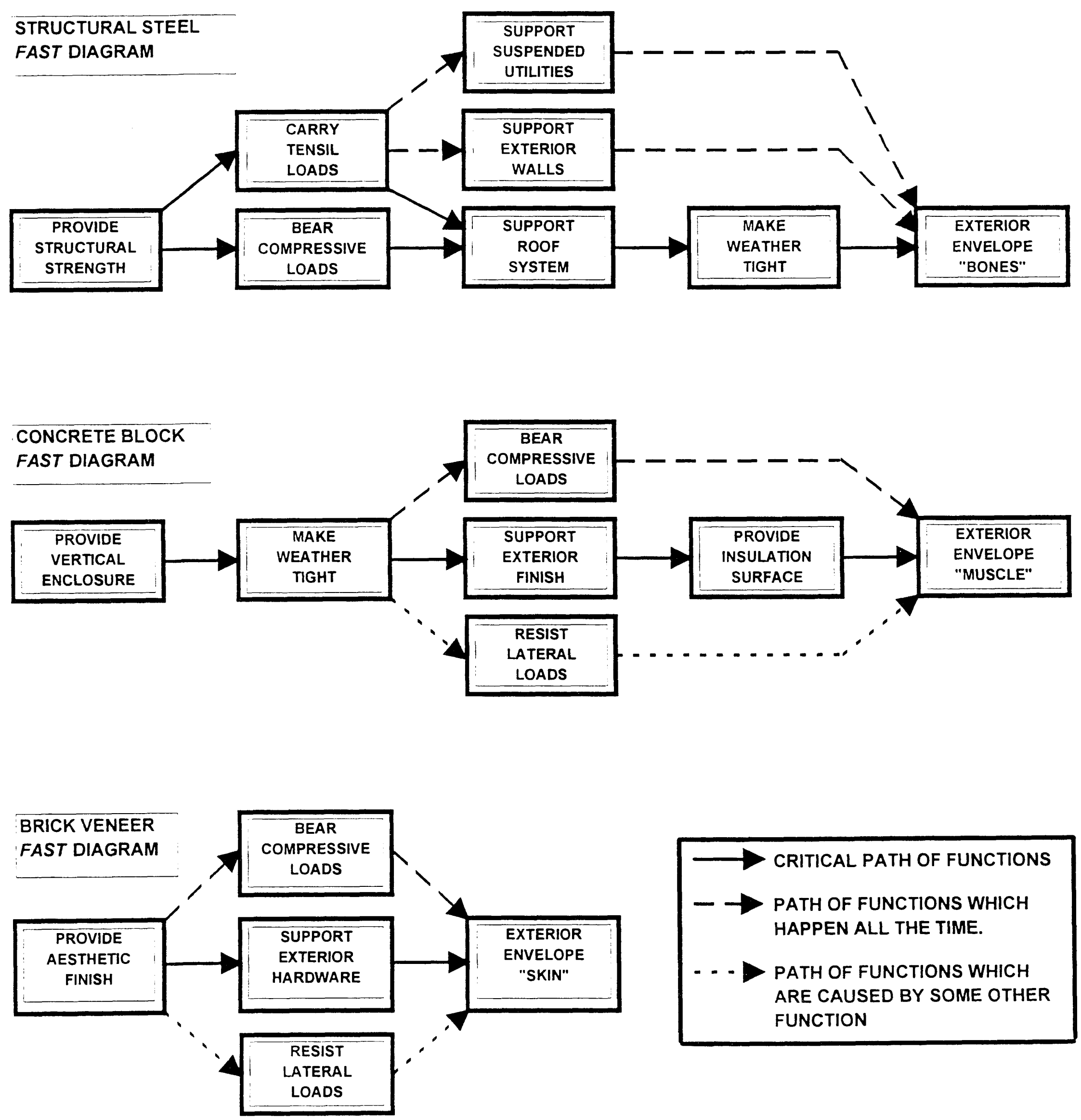


Fig. 1. Functional Analysis System Technique (FAST) diagrams for Current Design Approach.

(i.e., bear compressive loads) and only uses one, the steel, to accomplish that function. Therefore, the compressive strength capabilities of the concrete masonry unit and the brick is inherent to the completed structure but unused in the design. To say it another way, the designer has "paid" for capabilities that are not being used, and therefore has missed an opportunity to enhance the design's cost effectiveness by using the block and/or the brick for more than one purpose.

Figure 1 shows that brick can function as an architectural finish as well as a compressive load carrying material. Thus, as the brick has virtually no capacity to carry tensile loads, the steel must be retained and the brick integrated with the steel to perform the dual purpose of carrying compressive loads while acting as a final exterior finish. As a result, the concrete block can be eliminated altogether.

## PROPOSED DESIGN

Figures 2 and 3 are the conceptual design drawings from which the value analysis and cost estimate were made. The drawings illustrate a basic building with one side consisting of a single wythe brick "crinkle" wall and pilasters and a MBS providing the other three sides and the roof. The brick pilasters contain reinforcement and the main structural members of the MBS attach to the pilasters.

### As the Architect Saw It

Doug Gransberg contacted me to ask if I might be interested in developing a joint proposal for funded research from the Tusha Fund. This fund is managed by the College of Architecture and is aimed at "Innovations in Metal Building Systems." This is, of course a very general requirement and Doug had originally made an independent proposal that involved testing the actual structural strength developed between the steel column base plate and the concrete foundation subsystem. The hypothesis stated that if acceptable structural strength was developed sooner than was normally specified, the saving of time could be a significant factor in the estimate of project cost savings for the overall reduction in construction time. The proposal was not accepted because it was felt that, although it was a valid hypothesis, it was primarily quantitative and did not involve a substantive design component. We exchanged curriculum vitae and had an introductory meeting. Much of that time was spent telling stories about how well we had worked with other professionals in the past. We discovered that we both strongly disagreed with the simplistic stereotypes of architects as creative, but impractical, artists and engineers as pragmatic, but uninspired, human calculators. We successfully established a good level of mutual respect. In retrospect, this qualitative aspect of the joint research was very crucial to it's eventual quantitative success. Communication remained open through periodic meetings and phone conversations. We discussed different ideas for research. I mentioned that I was curious about the huge quantity of brick construction in the area, and equally curious about the great variety of metal building types being used both within Lubbock and in the small farming communities throughout West Texas. I was particularly interested in, what I imagined to be, the "thousands of miles" of brick sound barrier walls being used throughout the city as privacy walls. We discussed this and decided that some combination of those general thoughts would form the basis for our proposal. Doug wrote the first draft proposal and after passing it back and forth, we arrived at the following

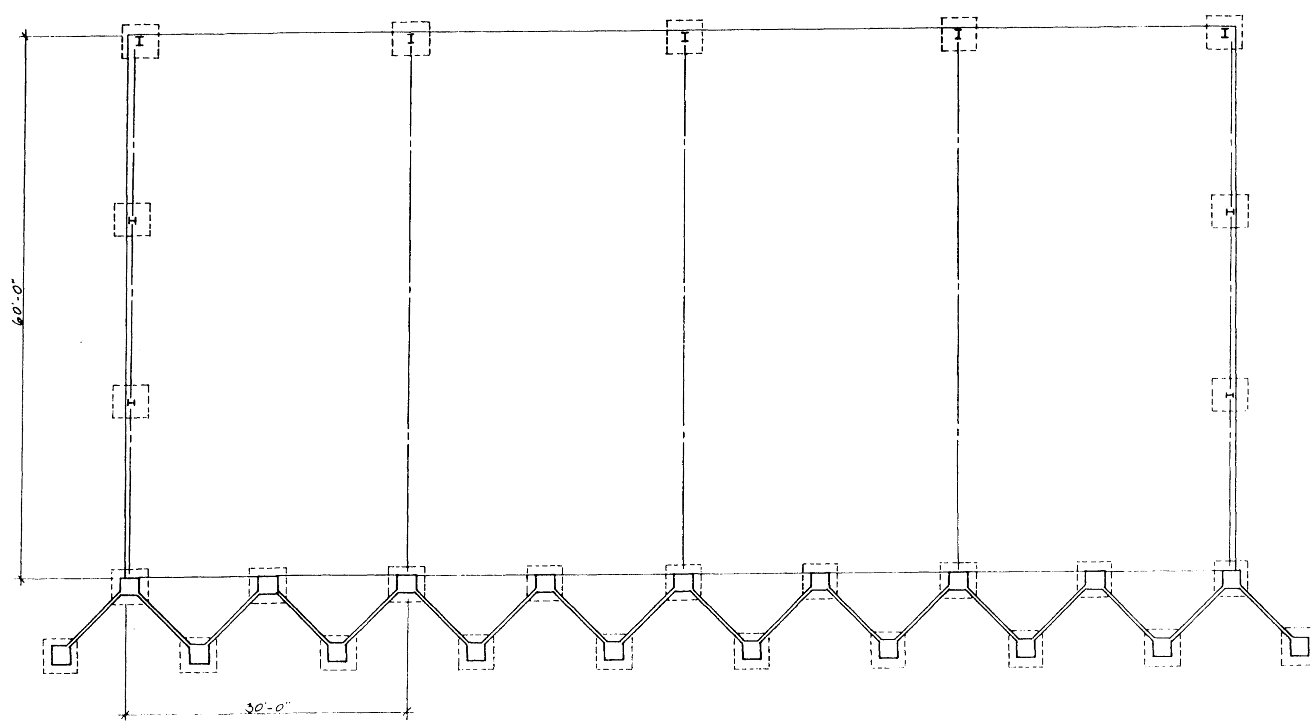


Fig. 2. Floor plan.

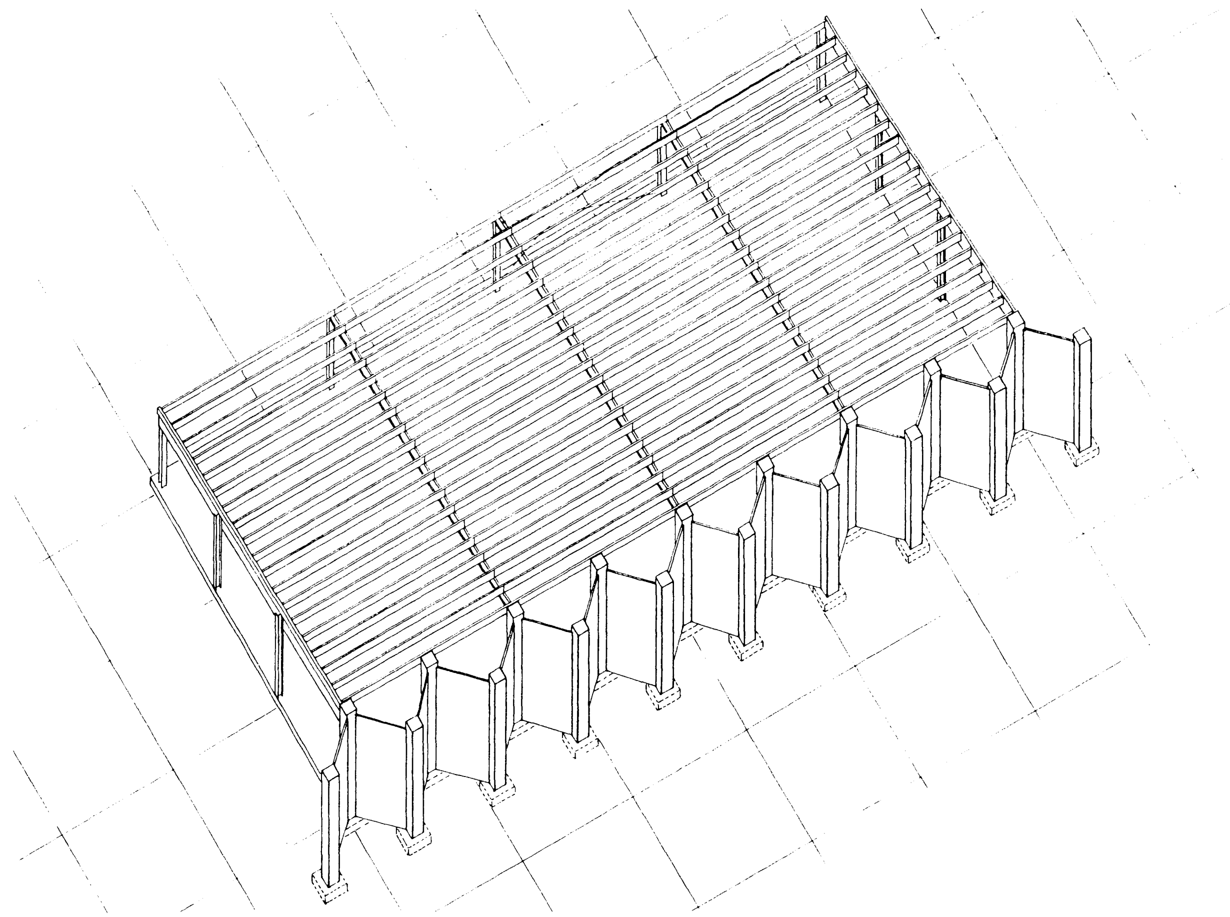

Fig 3. Axonometric.

proposal which was approved and funded: "Preliminary Design and Cost Analysis of a Pre-Engineered Steel Structure with Single Wythe Brick Walls for Use in Light Commercial Buildings - Phase I." In addition to reporting the research results we also decided to describe our impressions and approaches to the project.

As the Architect Designed It: In design, the power of limits becomes apparent as the limitations of the building program both frame the problem and spark the imagination. The challenge on this project was to establish a concept without a traditional programmatic direction. Normally, there is a specific client-user information base that includes site context and budget limits. In most cases, the critical information supplied provides keys to visualizing the building as a conceptual whole. It is through an informed intuition that good design emerges. Like an engaging story, the author conveys the quality of places and characters by understanding the vocabulary and grammatical rules appropriate for the setting. However, this project required a substitution of the traditional client-user program. Therefore, program research defined the construction vocabulary and appropriate grammatical rules of assembly for MBS and reinforced brick masonry construction (hereafter referred to as RBM). The design process aimed toward discovering simplicity within the apparent complexity of relating two highly distinct systems. The endeavor provided a clear-cut opportunity to demonstrate the intrinsic relationship between building technology and architectural expression [Wilson 1990, 11-16]. The proposal to explore innovative design possibilities for MBS led first to a review of the literature for steel construction. Additionally, the condition of a purely theoretical building project, without real site limitations and possibilities, allowed the imagining of the project within the Lubbock, Texas area. This locale provided a base of information regarding material and labor availability, costs, building customs, and the natural environment. The discoveries made during this research phase became a major part of the program requirements for the design.

The primary quality of MBS is that they are pre-designed and standardized. The metal building systems industry traces its concept back to the 1790's, when Eli Whitney developed the standardization of parts at his gun factory in New Haven, Connecticut [Buettner 1990, 1-4]. The physical characteristics of MBS have been determined, over time, by functional requirements of building use and the properties of steel. MBS allows only minor modifications without negating the concept of cost and time savings designed into the system. While systems allow for a limited amount of different building envelope shapes and many facade (skin) choices, these choices are a result of the original design parameters. The potential for variation is part of the program performance requirements for the engineer designers of the system. The concept of "system" was adopted by the industry in its approach to the fabrication and erection of buildings. Industry standardized structural frames, almost all enclosure elements, and construction methods to gain the advantages of mass production [Buettner 1990, 31-33]. The reduction in material waste, increased quality control, faster fabrication, efficient delivery scheduling and quick erection time are the advantages of the systems approach. Therefore, for this project, all standardized elements became possible candidates for inclusion into the physical design. The construction vocabulary and grammatical assembly rules of standardized MBS elements were accepted without modification. Conceptually, MBS were visualized as the space defining enclosure - "the space maker."

Observation of the general site context of the Lubbock, Texas area was conducted. It revealed that MBS were used for primary design benefits of fast erection time and low cost when compared to masonry construction. MBS were seen as primarily utilitarian. Building owners used them for such building types as farm equipment storage, warehousing, processing, and auto dealerships. They were not viewed as having the potential for beauty or permanence. On the other hand, brick masonry was an overwhelmingly prevalent building material. Observation noted that the community perceives brick, and masonry construction in general, as a high quality material that was used in such permanent building types as educational and commercial retail structures. One dominant application of brick veneer occurred on residential structures. The personal aesthetic attachment to brick in the general population dictated that virtually all new residential construction in the Lubbock area used brick. Therefore, the innovation, required for research proposal approval, became the new building relationship between brick masonry and MBS.

An additional literature search was conducted into brick masonry. A complete review of the *Technical Notes on Brick Construction* revealed specific information on three associated construction types of: single wythe noise barrier walls, serpentine garden walls, and RBM curtain and panel walls [BIA 1988-1991]. At the time of the first review, noise barrier walls did not seem an important consideration for inclusion into the mix of potential design elements. However, it was subsequently observed that many local builders were utilizing this type of wall as a privacy wall around entire semi-exclusive residential blocks. This indicated an abundant supply of both material and trained labor for this type of construction. The basic vocabulary of the walls consisted of reinforced single-wythe brick with grout filled, reinforced pilasters spaced at regular intervals. Grammatically, the reinforced pilasters were supported by pier-like foundations. The horizontally reinforced walls acted as diaphragm panels to connect the pilasters and to resist lateral wind loading. They required no foundation, but their span was limited to approximately twelve feet, due to the limitation of the horizontal joint reinforcement. The walls were being erected very quickly with a minimum amount of excavation. All the walls observed were of straight line configurations, built along the property lines, and bordering the site.

This led to the idea of combining the advantages of the time and cost efficient single wythe noise barrier wall, the self-supporting geometry of the serpentine garden wall, and the lateral load resisting quality of the single wythe RBM panel wall. The mental image of a folded sheet of paper turned on its edge sparked further development. This was transformed into pilaster "points" connecting brick "lines" at the fold. A full 90-degree zigzag of points and lines resulted in the innovation of the "crinkle wall."

Then, the new wall configuration was seen as a buttress, similar to Gothic construction. The semi-triangulated pilaster-buttress system provided the necessary support and resisted lateral forces. The overall width of the crinkle wall was also visualized as a thick spine, running the length of the building. It both housed and carried the primary plumbing, power, and HVAC systems. This allowed the "space making" MBS to be essentially free space and reduced the potential for costly penetrations of the MBS roof. Returning to the vocabulary of MBS elements, the pre-engineered lean-to section was reviewed. It had a shed-like configuration with a mono-directional roof frame pitch.

It depended on another structure for support at the high end of the frame. Normally, this support was the side wall column-beam frame of a standard MBS. Instead, the crinkle wall becomes the support. Similar to Christo's *Running Fence* sculpture, it would raise or lower, depending on the height of the lean-to steel frame and continue along its length to accommodate the number of framed bays. The lean-to spanned up to 60 feet. 25 foot spacing for a typical MBS was recommended for maximum cost efficiency. 30 foot spacing was acceptable. A review of literature for retail commercial space design recommended between 50 - 80 foot usable depth and a minimum 12 to 18 foot store width. [De Chiara 1990, 797] The basic lean-to frame configuration and general requirements for MBS met span and spacing requirements without modification. Since the crinkle wall has the inherent property of dimensional flexibility, it was adjusted to meet requirements of the building type and MBS. Understanding limits generated clarification and simplification of design. Respecting the construction vocabulary and system rules of both MBS and RBM resulted in the innovation of the metal building lean-to frame supported by the crinkle wall. Traditional approaches to design used brick and steel as either structural steel roof framing supported by a load bearing wall composed of reinforced concrete block with brick veneer or a complete MBS with non-load bearing brick curtain wall enclosure. This design appropriately used both materials systems as complementary vertical load bearing structures and the metal building system as the roof structure. This simplicity of use directly addressed primary connections between conceptual design, building technology, and construction cost. It did so by eliminating redundancy inherent in traditional methods, reducing perimeter foundations, and, most importantly, by fully integrating unmodified MBS elements. The success of the conceptual design warrants additional design development, including computer-assisted modeling, for physical form derivatives, energy use, and cost performance. Preliminary work was begun in collaboration with Professor Elizabeth Louden. She recently directed a preliminary analysis of the conceptual design elements, at the TTU College of Architecture, in her course: Computers in Architecture. This effort has started to establish the kit-of-parts, used in this design, for future design exploration. A detailed list of recommendations is included at the end of this report.

### As the Engineer Analyzed Its Cost

To conduct the cost analysis, several assumptions were made. First, we assumed that all aspects of the crinkle wall design's structural strength will be adequate. Obviously, this is something which will require further study. In fact, the single-wythe RBM wall's ability to withstand lateral loading is somewhat suspect and requires further research. However, the additional engineering and research effort is not warranted if this design concept does not offer a significant savings on which to amortize the front end research and development costs. The second major assumption deals with the costs of the current designs. We assumed that the costs found in current estimating manuals as adjusted by locality factors were representative of the actual design and construction costs to build the current designs [Means 1994, 198-201]. Thus there was no need to prepare a conceptual design for purposes of generating material quantities to drive the economic analysis. The "architect's fee" found in the estimating manual was reduced 5% to account for the savings in design cost attributable to the use of the MBS instead of structural steel or reinforced concrete block as well as to account for the engineering design costs contained in the basic metal building price. Third, research on light commercial buildings [Morse 1988, 50-52] led us to select a 60-by-120-foot building which provides four 1800 square foot retail spaces and assume that this size would be large enough to allow a representative conclusion to be drawn. Additionally, the cost analysis was restricted to the exterior envelope of the structure as it is the industry standard to require tenants to furnish interior build-out at their own expense. Lubbock, Texas was assumed as the site for hypothetical construction of alternatives. Finally, we assumed utility items such as plumbing and electrical power would have equal costs in every alternative and could be dropped from analysis.

Two current designs were analyzed and compared to three alternatives of the proposed design. The first current design approach (referred to as current alternative 1 or C1) eliminates the redundancy between the concrete block and the steel frame by eliminating the frame and allowing the block to take the compressive loads. Steel joists are used to support the roof and the block is again covered with a brick veneer as an architectural finish. The second is the structural steel frame and concrete block covered with brick veneer described in previous paragraphs (referred to as current alternative 2 or C2). The first proposed alternative (P1) consists of a MBS frame enclosed by a simple single wythe brick shell on three sides. On the fourth side, the same glass and metal storefronts used on one side of C1 and C2 are used. The

**Table 1: Cost Comparison of Alternatives**

| ALTERNATIVE | | C1 | | C2 | | P1 | | P2 | | P3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COST COMPARISON | | Brick/Block/Joist | | Brick/Block/Frame | | Brick Shell/Mtl Bldg | | Brick Front/Mtl Bldg | | Brick Back/Mtl Bldg | | |
| *Item/unit* | *Total units* | *Unit cost* | *Total* | *Unit cost* | *Total* | *Unit cost* | *Total* | *Unit cost* | *Total* | *Unit cost* | *Total* | |
| Foundation (SF-floor) | 7200 | 3.63 | 26136 | 3.40 | 24480 | 1.82 | 13104 | 1.82 | 13104 | 1.82 | 13104 | |
| Substructure (SF-floor) | 7200 | 2.05 | 14760 | 2.05 | 14760 | 1.90 | 13690 | 2.03 | 14613 | 2.03 | 14613 | |
| Superstructure (SF-roof) | 7225 | 5.94 | 42917 | 6.93 | 50069 | 5.88 | 42464 | 7.87 | 56877 | 7.87 | 56877 | [1] |
| Ext. Walls (SF-wall) | 3960 | 18.86 | 74686 | 18.86 | 74686 | 18.23 | 72173 | 13.90 | 55039 | 18.65 | 73838 | [2] |
| Doors & Windows (LS) | 1 | LS | 29844 | LS | 29844 | LS | 29844 | LS | 29844 | LS | 29844 | |
| Storefronts (EA) | 4 | 12500.00 | 50000 | 12500.00 | 50000 | 12500.00 | 50000 | 8635.00 | 34540 | 12500.00 | 50000 | |
| **Subtotal** | | | $238,342 | | $243,839 | | $221,275 | | $204,017 | | $238,276 | |
| General Conditions | 15% | | $35,751 | 15% | $36,576 | 15% | $33,191 | 15% | $30,603 | 15% | $35,741 | |
| **Subtotal** | | | $274,093 | | $280,415 | | $254,466 | | $234,620 | | $274,017 | |
| Architect fee | 8% | | $21,927 | 8% | $22,433 | 3% | $7,634 | 3% | $7,039 | 3% | $8,221 | [3] |
| **Total Cost** | | | $296,021 | | $302,848 | | $262,100 | | $241,658 | | $282,238 | |

[1] Metal building price which includes engineering costs.(P1,P2, & P3)
[2] Masonry crinkle wall & end walls (P2 & P3)
[3] Fee reduced to compensate for design costs contained in metal building price. (P1,P2, & P3)

second proposed alternative (P2) uses a RBM crinkle wall as the front of the structure and as a result requires a different size storefront than the other four alternatives. The third proposed alternative (P3) uses a standard storefront on the front of the building and puts the crinkle wall at the back of the building.

## RESULTS

Table 1 shows the results of the cost analysis. While all three proposed design alternatives clearly demonstrated their value, the cost analysis contained a couple of surprises for the analysts. First, by using a MBS structural package with a 60 foot interior clear span, the number of spread footings was cut in half. Consequently, cost savings were realized on the foundation which were not initially expected. On the other hand, the savings expected by eliminating the concrete block were only realized in Alternative P2, the brick shell. The other two alternatives minimally decreased the cost of the exterior walls over the existing systems. This is due to the design of the single wythe RBM crinkle wall itself. In fact, this design involves a total of over 5000 square feet of brick as compared to 3960 square feet of brick veneer on the two current designs. Of the roughly $18 per square foot unit cost, over $12 was due to the brick. Alternative P2 has a large proportion of the total frontal area occupied by the storefronts. Thus a good deal of RBM was eliminated and the anticipated savings from eliminating the block was realized. Thus it can be concluded that there is an optimum amount (perhaps a break-even point) of brick face area which can be used over which potential savings on the block is eroded to nothing.

Further savings are realized by the use of the MBS as the primary structural frame. Although it is not readily apparent in alternatives P2 and P3 due to inclusion of certain design costs in the MBS price, it can readily be seen when P1 is compared to C1 and C2. The issue of design cost savings is central to this VE study. As this is the last mark-up, the percentage selected to represent design costs in the form of an architect's fee can become quite contentious. A sensitivity analysis was conducted to test the assumption made in the initial analysis. The results are shown in Table 2 and quite clearly show that even if the architect's fee was assumed to be equal in all cases (i.e. totally discount the level of design cost which is contained in the MBS price), all three proposed alternative designs would still be competitive on a bottom line basis with conventional alternatives.

## CONCLUSIONS AND RECOMMENDATIONS

The numbers show that this design configuration of the single wythe RBM wall and the MBS steel structure promises significant savings for this building use type. Not only are the savings found in material and construction costs but the use of an off-the-shelf standard metal building also reduces the overall cost of design. Because of the cost savings potential, additional engineering design analysis and material testing to prove the fundamental integrity of the approach is justified. Therefore, the following research recommendations are made:

1. Computer-assisted modeling to optimize building form. This would include optimization of cost as related to materials and methods of construction and energy consumption. Modeling would aim to generate a series of viable alternative combinations of MBS and single wythe RBM walls.
2. Testing and analysis of the single wythe RBM wall to determine its ultimate capacity to resist lateral loading is warranted.
3. Testing and analysis to determine the optimum spacing between single wythe RBM wall pilasters is warranted.
4. Further Life-cycle cost analysis which includes operations, maintenance, energy conservation and overall sustainability should be conducted and compared with current practice to determine if additional savings or latent costs are inherent in various designs.

## Table 2: Architect's Fee Sensitivity Analysis

| Item | Alt | P1 | P2 | P3 | C1 | C2 |
|---|---|---|---|---|---|---|
| Direct Cost + Overhead | | $254,466 | $234,620 | $274,017 | $274,093 | $280,415 |
| Total Cost with Architect's Fee @ | 3% | $262,100 | $241,659 | $282,238 | | |
| | 4% | $264,645 | $244,005 | $284,978 | | |
| | 5% | $267,189 | $246,351 | $287,718 | | |
| | 6% | $269,734 | $248,697 | $290,458 | | |
| | 7% | $272,279 | $251,043 | $293,198 | | |
| | 8% | $274.823 | $253,390 | $295,938 | $296,021 | $302,848 |

5. Determine the break-even point for optimum area of single-wythe RBM as compared to concrete block with brick veneer.

## ACKNOWLEDGMENTS

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