The Human Anatomy of Construction

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Abstract

Many components make up the anatomy of a structure. Structural components, such as columns, beams, slabs, and floors constitute the building units of what is usually referred to as the skeleton. But the "human" anatomy of structures is more important than, and directly affects, their physical anatomy. The design of a structure and the method used in construction are influenced by social, cultural, religious, and historical factors. In addition to these human factors, building design must take into account the prevailing natural, environmental, and engineering conditions. In the absence of careful consideration of the full array of factors, a structure could lack the desired functionality. Construction for Humanity is a course developed and offered at Union College with several goals in mind. The most important is to show the seamless connection that exists between Liberal Arts and Engineering. This is demonstrated using numerous examples of ancient and modern structures in an interdisciplinary fashion. Topics covered in this course include earth and masonry structures, domestic housing, castles, cathedrals, monuments, dams, bridges, roads, tunnels, skyscrapers, and structures with futuristic designs. Weekly assignments and a carefully crafted project complement and enhance the students' learning experience.

I. Course Idea

The second author (A. Ghaly, an engineer) approached the first author (S. Sargent, an historian) and explained his idea of a combined course which would explore the engineering and humanistic side of structures throughout history. Sargent was very enthusiastic about the course, because he recognized immediately its potential for real interdisciplinary cooperation. Both authors agreed on the basic course outline after a few hours of intense discussion. After that it was all implementation. Sargent believes that engineering students should consider the historical, social, and cultural aspects of buildings, because engineering doesn't happen in a vacuum. All structures are influenced by cultural expectations about how a building should look and how it will be used. Social structure, gender relations, religion, and aesthetics (to name just a few factors) all play a role in building design. In fact, in most cases cultural factors are more significant than material constraints in determining a building's form and function. It is also important for engineering students to consider social uses of buildings because this will help them design buildings which better satisfy the needs of the inhabitants. Furthermore, although the design of buildings is meant to make them structurally safe, an understanding of the social use of buildings will also make them comfortable and enjoyable.

The course was supported by a National Science Foundation (NSF) grant which provided the impetus for developing the course. The authors believe that unless the college or university provides significant stimulus to create new interdisciplinary courses, faculty will perceive little incentive in the institutional reward structure to justify the investment of time and effort interdisciplinary courses require. The synergy produced by the cooperation of faculty from different disciplines helps expand both the professors' and students' understanding of the world. Therefore, it is the authors' opinion that institutions need to help unlock the creative power of their faculty through interdisciplinary courses. It is also important to make sure that the institutional reward structure will stimulate both the creation and continued teaching of interdisciplinary courses.

II. Course Major Themes

The course addressed six major themes, which were selected to show how the use of materials in the construction industry has progressed throughout history.

1. Earth as a construction material

Earth (soil) was one of the early construction materials found in abundance which could be easily processed and molded into desired shapes. It can be used in large structures, such as dams, or as small structural component, such as masonry or bricks. The type of earth available in a given region, however, limits the type and scope of applications. The relationship between construction and earth throughout history is explored. The historical and engineering perspectives begin with the origin of human construction and consider to the following points:

- The need for shelter.
- Building materials.
- Environmental factors.
- Building techniques.
- The emergence of villages and urban civilization.

2. Domestic housing in the Ancient World

Small houses in which ordinary people spent most of their lives have seen constant changes in style, method of construction, and construction materials. These factors are examined together with their influence on improving people's lives. The historical and engineering perspectives cover Near Eastern, Greek, and Roman housing through the following points:

- Construction in the Fertile Crescent: Sumer and Babylon.
- Greek and Roman Domestic Housing.

3. Large domestic and public structures: castles, cathedrals, and palaces

In many societies wealthy secular or religious elites have used their power to build imposing structures designed to enhance their status. In Europe the transition from wood to stone as a primary construction material is especially evident in this category. Three historical and engineering perspectives are covered:

- Castles: From Wood and Earth to Stone.
- Cathedrals: Pointed Arch and Flying Buttress.
- Palaces in Renaissance Florence.

4. Uninhabitable structures such as monuments and dams
Civilizations throughout history dreamed of ways to commemorate their achievements. Construction of monuments was one way to achieve this goal. Although monuments are uninhabitable structures, they were always used to symbolize what nations attempted to achieve. The historical and engineering perspectives cover the following points:

- The Egyptian Pyramids.
- The Eiffel Tower.
- Hoover Dam.

5. Large structures over gaps or waterways (bridges) or underground (tunnels)
Different civilizations viewed waterways or mountains as obstructions crippling or reducing their progress. Bridges and tunnels were thought of as possible solutions to connect different people, encourage commerce, or establish new communities. The social and historical implications of bridge and tunnel construction have been enormous, and this course covers both the engineering and human aspects of large structures.

- Bridges: The Brooklyn Bridge.
- Tunnels: The Channel Tunnel.

6. Large workplace structures such as factories and high-rise office buildings
These two types of construction are examined in terms of how they change the workplace. The historical and engineering aspects of these structures are covered from the following perspectives:

- Factories in nineteenth-century America: Lowell, Massachusetts.
- High-rise office buildings: The Empire State Building.

An additional theme was addressed in the end on the course. Futuristic structures are new structures with unusual shapes and design. They may be built to make an architectural statement or to be different and distinguishable from other structures. Examples of structures with futuristic design addressed in this course are:

- The Guggenheim Museum, New York City.
- The Weisman Art Museum, Minneapolis, Minnesota.
- The Guggenheim Museum, Bilbao, Spain.
- Experience Music Project, Seattle, Washington.

III. Course Logistics

Interdisciplinary courses are desirable because they provide students from seemingly contrasting disciplines the opportunity to discover the interdependent nature of engineering and the humanities. They also serve an important purpose in an increasingly globalized world, where cultural and social factors do indeed matter when it comes to building design. It is, however, important to note that interdisciplinary courses come at a huge cost in time. The hours needed to prepare class lectures, notes, presentations, and to provide guidance to the students are enormous. This is due to two reasons. (1) The student population in such courses is usually divided into two camps: those who are technically strong but not as knowledgeable in the humanities and social sciences, and those who are just the opposite.

Striking a balance and satisfying both groups is certainly a challenging task. (2) Requiring the students to publish their assignments and project reports on the Internet proved to be an overwhelming but positive experience for the majority of them, despite the many technical sessions and the personal guidance that were made readily available to them. The time the instructors commit to such classes could become a real burden on other classes or other responsibilities they might have.

All lectures took place in electronic classrooms and featured large-screen computer, video, and CD-ROM presentations. An extensive handout was prepared for each class. Both authors cooperated in every aspect of the course: they were together in class in every session, always reviewed the materials to be presented, and created a two-man show in which they complemented each other in everything they said and did.

IV. Assignments and Project

Students were given the choice either to hand in their assignments in hardcopy or to post them on their own homepage. Every student at Union College has a disk space on the college's server. The course instructors offered a tutorial on posting material on the Internet, in addition to unlimited help outside of class. The project in this course, however, was Internet-based. Called *Humanstruction*, the project required each student to pick a subject of interest within the framework of the course and write a research paper on that subject. Students had to post their projects on their respective web sites for peer and instructor evaluation. While the project could also include pictures, graphs, charts, or tables, it had to contain at least 10 pages of text. In addition to the instructors' evaluation, all assignments and the project were peer reviewed. Reports were required to emphasize the engineering and historical aspects of the subject under consideration. Grading criteria emphasized grammar and style, organization, content, and quality of presentation.

Each week six students were randomly selected to make presentations on the topic of the week. Presenting students were assigned grades based on the quality of their presentations as evaluated by the two instructors and by two randomly selected peers of each presenting student. The use of weekly student presentations, including evaluation by both students and instructors, helped create a much more open and lively classroom atmosphere. Students not only learned the material, but also learned how to present their ideas. This teaching technique can be carried over to other classes, making the students more engaged with the material and comfortable with the use of electronic presentation styles. All student projects were required to be posted on the College's Web server for peer and instructor evaluation. One major goal of the course was to increase the students' familiarity with and willingness to use software for electronic presentations.

V. Engineering Aspects

Considering only the engineering essentials, the structure of a building can be defined as the assemblage of those parts that exist for the purpose of maintaining shape and stability. Its primary purpose is to resist any loads applied to the building and to transmit those to the ground.

In terms of architecture, the structure of a building is and does much more than that. It is an inseparable part of the building form and to varying degrees is a generator of that form. A structural system is engineered to maintain the architectural form. Therefore, structures for buildings must be rational in terms of their adherence to the fundamental principles of science.

At least three items must be present in the structure of a building: stability, strength, and economy. Taking the first of the three requirements, it is obvious that *stability* is needed to maintain shape. An unstable building structure implies unbalanced forces or a lack of equilibrium and a consequent acceleration of the structure or its pieces. The requirement of *strength* means that the materials selected must be adequate to resist the stresses generated by the loads. *Economy* of a building structure refers to more than just the cost of the materials used. Construction economy is a complicated subject involving raw materials, fabrication, erection, and maintenance. Design and construction labor costs and the costs of energy consumption must be considered. Speed of construction and the cost of money (interest) are also factors. In most design situations, more than one structural material requires consideration. Competitive alternatives almost always exist, and the choice is seldom obvious.

Definition of Structure

The word *structure* has many meanings. Dictionaries usually define it in very general terms, such as the following: “the organization or interrelation of all the parts of a whole; manner of construction.” Structures or structured things exist almost everywhere, and any definition will apply more aptly to some than to others. Without confining the use of the word to buildings or other engineered objects, we find that almost everything has structure. It is very difficult to think of anything that is totally without structure. Certainly, every material object has a basic molecular structure, if nothing else. It is imperative to stress that in this course and all related studies, we are dealing with a very specific and narrow use of the term.

Cost of Structure

The course discusses the following factors relating to construction in detail.

- Costs of materials, fabrication, and erection.
- Availability of materials, needed construction trades, transportation costs.
- Ambient environmental conditions.
- Severe weather conditions.
- Life-cycle cost of one system compared to another.
- Cost of superstructure versus cost of foundation (soil conditions).

Modern Structures

Factors affecting the cost of modern structures are listed below. Although many of these factors do not have direct impact on the stability of structures, they all affect, to different degrees, the level of comfort and enjoyment of a structure’s inhabitants.

- Engineering and licensing fees.

- Mortgage.
- Insurance.
- Mechanical systems (elevators, escalators, pumping, etc.).
- Electrical systems (elevators, escalators, pumping, alarm, surveillance, etc.).
- Fire protection.
- Heating.
- Air conditioning.
- Ventilation & dust collection systems.
- Telephone, cable, Internet, intercom, video, and fiber optic circuits.

Building Codes

Various codes and specifications provide data on:
- Design loads,
- Allowable stresses in materials,
- Properties and dimensions of standard cross sections,
- Standard design procedures,
- Construction tolerances,
- Factors of safety.

The intent of all building codes is the protection of the health, safety, and welfare of the public.
The provisions of a code generally represent minimum acceptable standards and not design ideals.

VI. Humanistic Aspects

The fundamental humanistic perspective presented in the course is the idea that human beings form their built environment to meet both their physical and cultural needs. In some places resources and technological expertise are so limited that the little leeway exists for people to vary the forms of their dwellings and public buildings. But in most historical societies this has not been the case: the material and technological constraints have allowed people room to express their cultural preferences in structures built both from necessity and by choice. In the first unit of the course the instructors showed how earth could be used in manifold ways to construct housing units, religious edifices, shops and bazaars, and city walls. Examples were taken from many different societies: the ancient Near East, Africa, Asia and India, the American Southwest, Mesoamerica, and even Australia. These examples showed how, despite the limitations of earth as a structural material, human societies have created numerous different styles of buildings adapted to climate conditions, social necessity, and the need for cultural expression. Some of the most attractive and useful buildings the students studied were made of earth.

The importance of housing for human populations led the instructors to examine in detail the domestic structures in the ancient world. Three societies were chosen for study: the city of Ur in Sumaria, ancient Greece, and the Roman towns of Pompeii and Herculaneum. Students learned that each society employed a similar form for their basic domestic unit, the courtyard house, but each varied the plan according to their needs. In Ur the need to separate the family from the outside world led to an inward-looking design that provided a haven of peace and quiet away from the busy streets and bazaars. In Greece, the need to limit contact between women of the family and men who weren't their kinsmen led to forms of gender segregation based on separate men's and women's quarters. In Rome this gender segregation broke down, and the basic courtyard house was elaborated into a multipurpose building used for business, entertaining, and private domestic functions. The remains of the Romans houses at Pompeii in particular provide many examples of how cultural needs led to changes in housing design. In addition, the use of new building materials, especially concrete, allowed Roman builders to create much more elaborate and stable structures.

Castles and cathedrals also provide ideal opportunities to illustrate the influence of culture on construction. Castles are defined as fortifications that are also houses, and their social function is to reinforce the power and authority of military elites. Using examples from medieval Europe and Japan, the course showed how castles expressed the "architecture of power," allowing rulers both to withstand invasion and dominate their subjects. From the point of view of construction, however, castles evolved continuously, moving from wood and earth to stone, and employing new and stronger elements to counter changes in armaments and siege techniques. Cathedrals expressed the wealth and power of the Church and its control over the intellectual life of society. Like castles, they developed from wood to stone structures, while innovations in building techniques and the empirical understanding of how to distribute loads led to a rapid expansion in size and complexity of Gothic cathedrals. One of the most important outcomes of these changes was the development of the artistic and religious programs of stained-glass windows, which offer an ideal example of the connection between engineering and cultural innovation.

Not all the buildings studied had to do with everyday life. The course also examined how societies use monuments to express their greatness and commemorate their achievements. The pyramids were primarily burial chambers, but they offer students many possibilities for studying the effects of wealth, power, and religious beliefs on construction. In addition, they demonstrate the sophistication of building techniques in a society remote from the modern age. From a more recent era, the Eiffel Tower also illustrates the connection between monumental building and engineering innovation. The combination of human ingenuity and careful attention to form and fabrication makes the Eiffel Tower a textbook example of how humans build not only for necessity, but also out of pride and ambition.

Beginning with the Eiffel Tower, the course deals mainly with the achievements of the modern era. Innovations in the kinds of structures necessary to the function of commercial and industrial societies take center stage. The Hoover Dam is studied as an example of engineering achievement on a previously unimagined scale with the help of massive government support. The history of bridges is surveyed, and the building of the Brooklyn Bridge is used as a paradigm of the application of engineering innovations to solve the problems of spanning ever-larger spaces. Students learn not only about types of bridges and how they are built, but also how societies around the globe have competed to demonstrate their technical expertise and gain prestige by constructing longer spans. The same approach is taken to the study of tunnels: the Channel Tunnel is examined in detail, but tunnels on every continent except Antarctica are surveyed to illustrate the range of human endeavor and ingenuity.

Skyscrapers, office buildings and factories are quintessential products of the modern industrial era, and the evolution of their size and forms is one of the key stories of the previous hundred years. For skyscrapers the Empire State Building is the primary object of study, but the developments of the last sixty years, including the world-wide competition to build the largest building, are chronicled rather thoroughly. Attention is also paid to the transformation of the work place in with the beginning of the factory system, especially in nineteenth-century New England. In future versions of the course the changing nature of the workplace will be explored in even greater detail.

Finally, the course attempts to highlight human ingenuity by examining current trends in construction and the possibilities for the future. The form, materials, technology, and cultural significant of several futuristic structures are used to illustrate what is happening now and give some suggestion about where construction is headed. Although speculative, this element of the course is one of the most exciting for students about to join the world of work.

Considerations of culture and society are thus build into every unit of the course. Engineering and humanistic considerations are presented as complementary elements in the construction decisions of every society, from the ancient Near East to the modern world. Both approaches are fully integrated into the methodology of the course.

VII. Experience and Challenges

The authors were gratified to observe students' fascination with both the engineering and the humanistic aspects of construction. Engineering students find it refreshing when they learn about the cultural, social, and environmental factors that affect the design procedure and the relevance of such factors to the location in which the structure is constructed. This increases the "human component" of otherwise technically-oriented presentations. The students from the humanities find pleasure in learning about some light technical matters related to the construction of buildings in general and unusual ones in particular. The authors also noticed that students' questions after class presentations showed a keen interest in the subject matter and a desire to learn more about structures and the way they are constructed.

The most challenging aspects of the course were: (1) work load, especially creating two digital presentations per week, with images and text, plus a separate ten-page handout on average; (2) providing enough technical content to satisfy the engineers without overwhelming the humanists, and providing enough cultural content to satisfy the humanists without boring the engineers. Generally speaking, the main challenge was to mix the two student cultures into a single educational experience. Two thirds of the students in the course were humanists and one third was engineering students.

The personal satisfaction the authors experienced while working together was the best reward of all. They learned from each other, and their combined enthusiasm helped energize and excite the students.

VIII. Conclusions

1. Provide incentive to faculty to commit the time and the effort such courses require.
2. Provide recognition to faculty who are willing to go the extra mile to make the students' learning experience rewarding and pleasurable.
3. Approach faculty who work well together and encourage them to develop courses of mutual interest. Matching personalities is a key point to ensure the success of such courses.
4. Do not allow faculty who are not serious to take advantage of the offered incentive, because this will dishearten the faculty who do a quality job.

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