AC 2007-313: EVALUATING STRUCTURAL FORM: IS IT SCULPTURE, ARCHITECTURE OR STRUCTURE?

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Evaluating Structural Form:
Is it sculpture, architecture or structure?

Abstract

The purpose of this paper is to discuss the idea of a continuum between sculptural form, architectural form and structural form. A linkage between the various forms will be proposed, and several scholarly views on this subject will be presented. Then, this paper will describe a brief web-based survey which tested people's subjective categorization of various sculptural, architectural and structural forms. The target audience of the web-based survey was college students interested in building design and high school students. Finally, this paper will analyze whether or not presenting the respondents with the idea of a proposed continuum between such forms left a lasting impression on them.

A Continuum of Form

Professor David Billington has proposed that sculptural form, architectural form and structural form are linked in a continuum[1]. All three of these forms are designed, three dimensional structures. Certainly the dividing lines between them can be blurred. Yet there are hallmarks defining each of these three types of form that can be generally agreed upon.

Sculptural form is created by an artist who is interested in exploring aesthetic and formal possibilities in three dimensions. The Swiss architect and Bauhaus artist Max Bill said that the art form of sculpture can be "essentially identifiable as invention…the invention of a means of expression"[2]. Sculptural form can be figurative, for example it can represent some other form. Other sculptures look random, with only the slightest sign that the form was made by an artist. Yet a common denominator in sculptural form is that it is meant to be an aesthetic work, not a functional structure. And it must be three dimensional, and stable and strong enough to carry its own weight.

Architectural form is

> dictated by architectural purposes, such as the practicalities of spatial organization and control of the flow of occupants. Architectural form is also concerned with the sense of space a structure creates, its symbolism and its relationship to its setting"[3].

Certainly architectural form can lean toward sculptural form as in the case where architectural "elements are exaggerated or when forms reflect a nonefficient use of

material just for the sake of emotional impact"[4]. But architectural form is always at least somewhat functional, it is always three dimensional and typically it is client driven. It must satisfy the needs of the client and the occupants, yet it also must satisfy artistic and creative goals of the architect. Finally, it needs to be safe, since it ultimately will be used by people.

Structural form is

> dictated by structural needs, primarily to support gravity and lateral loads, and usually also the need to provide a building envelope for shelter against the elements. Carefully designed structural form can exhibit the stark beauty of controlled strength, even to the point of excitement. Structure can define the visual impact of a building, as in the case of large exposed columns which give the appearance of strength and solidity, or the case of tall slender columns which can create an elegant loggia effect.[3].

Structural form is mathematically based, it seeks the greatest efficiency, economy and elegance that the designer can create. It is not random, it is not generated by trial and error, it is not subject to changes in taste or fashion, it is not symbolic of some anthropomorphic idea.

Educator and architect Seymour Howard explored some of the linkages between sculptural form, architectural form and structural form as early as 1966[4]. He derided architectural form that veers toward sculptural form as that whose

> dimensions and geometry are chosen, not because of limitations of material, workers' skills etc. but often in spite of these very limitations. Structure is made subservient to a design which finds its logic in the architect's particular aesthetic thought[4].

Howard labeled such architectural forms as "sculptural structure" and consequently, they would fall somewhere between sculptural form and architectural form on our proposed continuum. The categorization of such a form on a larger continuum is perhaps a more

clear definition of this type of form than Howard's term "sculptural structure". It is such categorizations that we have sought to explore in the web-based survey.

Other writers have more recently criticized this blurring between sculptural form and architectural form. A particularly eloquent if acerbic critique of this blurring came from the British writer and lecturer Charles Jencks who said that such works

> typify the case of an architect, not especially trained as an artist, who intends to make a grand sculptural gesture that has never been seen before and yet still make something functional. Caught between opposite requirements, pushed by celebrity culture one way, and pulled by a utilitarian philosophy the other, he may be blind to emergent blooper…function plus unlikely gesture equals a screw-up[5].

Deyan Sudjic, the architecture critic for the *London Times* recently wrote extensively about the "push by celebrity culture" to shape current architectural forms. He wrote that

> architecture has always been dependent on the allocation of precious resources and scarce manpower. As such, its execution has always been at the discretion of those with their hands on the levers of power rather than of architects[6].

Both Sudjic and Jencks decry the "blatant exhibitionism" of some of the sculptural or pseudo structural forms of contemporary architecture, with particular venom targeted towards Santiago Calatrava who pushes architectural form towards structural form, but in a way that is "stereotyped, produced on the run, quickly built, guaranteed high style, compressed as an image, and of course, inflated in size and self-importance[5]. These comments call to mind the much earlier critique of Howard who said that such "pretentious structure is the label for 'structure for structure's sake' when aesthetic sensitivity is lacking and when novelty of form is the only claim for attention".[4]

The educator and critic Witold Rybczynski also critiqued the failed attempt by clients to make grandiose architectural icons. He exposed France's President Francois Mitterrand's multibillion dollar *Grand Projet* program of national icon building as a failure, as well as Microsoft billionaire Paul Allen's sponsorship of Frank Gehry's Experience Music

Project in Seattle as “confused and confusing, a mishmash of forms, materials and colors that tries too hard to be a literal representation of rock and roll and falls flat”[7].

The educator and structural engineer Andrew Charleson has written about the juncture between architectural form, which he defines as the “massing or the enveloping form” of a building,with structural form which he understands to be “a building’s primary or most visually dominant structural system.”[8]. He argues that exposing structure in a building can trigger the designer’s imagination and “suggest ways for them to further develop their individual ideas”. This “transformative power of (exposed) structure” can create design opportunities and in fact, be the starting point for overall architectural form.

The distinguished structural engineers Charles Thornton and Richard Tomasetti similarly call for designers to rationally expose structure in their architectural forms, but they go further and long for expressed structure, not simply exposed structure[9]. Their definition of expressed structure is structural form that can be viewed and understood by an informed observer. Decorative columns that suddenly stop, ornamental cornices and the like may be exposed structure, but they make no structural sense, thus they do not express any structural ideas.

Such ideas about exposed or expressed structure can be found in many other writers’ works, from the early writings of the French architect and theorist Viollet-le-Duc who argued for Structural Rationalism, through the classic works of the architectural historian Carl Condit who found “architectonic expression” in the rationalism of the Chicago School of architecture. Great structural engineers such as Pier Luigi Nervi and Fazlur Khan have also written on this topic. Nervi said that respecting what is structurally rational and economically prudent actually establishes the “correctness” and the “ethics” of building[10]. Khan argued that

> well detailed and efficient structures posses the natural elegance of slenderness and reason, and have possibly a higher value than the whims of a-priori aesthetics imposed by architects who do not know how to work closely with engineers, and who do not have an inner feeling for natural structural forms.[11].

What Links the Three Forms Together

The linkage between these three forms can be summarized as increasing constraints imposed on the designer, as one moves from sculptural form, through architectural form,

to structural form. Another way of looking at this linkage is to say that there are increasing freedoms for the designer as one moves from structural form, through architectural form to structural form.

The increasing constraints are varied. There may or may not be a client involved in sculptural form, there is typically no function associated with sculptural form, except for certain kinetic sculptures. The designer is free to make any and all decisions about the form, with virtually the only constraint being that the sculpture must stand on its own.

Architectural form has more constraints imposed on it than does sculptural form. Architectural form typically must satisfy client desires, it must fulfill the spatial, organizational and practical safety issues that are required of architectural structures. Yet it has fewer economic and mathematical constraints on it than does structural form. Especially in today's design world of sophisticated finite element analyses, architectural form has greater latitude, it swings between sculptural form and structural form, with mixed results as evidenced by the aforementioned critiques.

Structural form has the greatest amount of constraints imposed on it, and consequently the least amount of freedom. Structural engineers who create structural form are primarily concerned with safety, economy and constructability of the form. These are quantitative concerns that can be measured and optimized. When a master structural engineer embraces the discipline required of structural form in conjunction with the freedom of personal creativity, then a work of structural art may emerge.

Billington has proposed that the designer of three dimensional form, be it sculptural, architectural or sculptural, is always concerned with the scientific, the social and the symbolic aspect of the design[1]. The scientific dimension recognizes the need to satisfy the laws of nature, built forms must withstand self weight and applied loads, they must be stable, they must resist weather and the effects of the environment. The social dimension of built form allows for the fact that built forms have a role in the social, the political and the economic climate of our society. The symbolic dimension of built form is concerned with the emotional impact of the form, its visual power and its expressive strength.

By superposing Billington's symbolic, social and scientific dimensions onto the continuum of three dimensional built forms, it becomes clear that that the sculptor is primarily, but not exclusively concerned with the symbolic aspect. The architect's primary, not sole concern, is the social aspect. And the structural engineer's primary criterion is the scientific, but the engineer must also consider the symbolic and social aspect of the built form.

Thus, we see the ever increasing dominance of the scientific aspect corresponds to an increasing set of restraints as we move from sculptural, through architectural to structural form. Yet this does not imply that the structural designer's hands are tied, but it does mean that structural creativity must spring from an ever increasing economic and scientific set of challenges. Designers of architectural and sculptural forms also have these constraints, but they are less severe.

A Web-Based Survey Categorizing Form

The purpose of the web-based survey was two-fold. The first purpose was to see if any trends existed in the responses of architecture students, architectural engineering students, civil engineering students and high school students, as they categorized five different structural forms. The second purpose was to see if the brief introduction of didactic material, as is found on a museum panel for instance, could actually inform the reader of a fairly complicated idea (the continuum of 3D form) in a very succinct manner.

Thus the strategy of the survey was to first have the respondent identify his or her field of study. Then the survey showed five somewhat similar images. We decided to use only non-habitable tall slender towers as our forms. The reasoning was that we needed to control variability as much as possible and not introduce a wide range of structures. After viewing the five forms, the respondent was asked to categorize them as sculptural, architectural or structural form, but to do so without any guidance or prompting from the survey. Then, a brief educational panel of material presented the previously described continuum of three dimensional forms and the linkage of increasing constraints. After this presentation, the respondent was asked to once again categorize the forms. After analyzing the results of all respondents, we saw insignificant differences between the first and the second rankings.

Designing such a survey is fraught with challenges. It was quickly discovered that it is very difficult to not present "loaded" questions, i.e. questions that lead the respondent in one direction or another. The choice of forms was challenging, what to choose, how many to use? Certainly one could argue endlessly about the choice of forms, was one too obvious, was one too vague in its "location" on the continuum of three dimensional forms? Practical issues of the design of the web interface, permission for images, publicizing the survey, encouraging students to actually fill it out, all these issues took some time to master. And ultimately, we understood that this is an entirely subjective survey, there really are no correct answers!

The chosen five towers merit some explanation. All were tall, slender, non-habitable towers. All had some features that could reasonably merit categorization in more than one slot. The purpose of this was to not make the choices too easy, but in retrospect, perhaps the choices were too difficult because there are no clear outliers. An attempt was made to avoid extremely well known towers, the Eiffel Tower for example. Tower #1 is a 30 m tall hyperbolic paraboloid thin shell concrete water tower. It was built in 1965 in Moglingen Germany, with architectural design by R. Kessler and structural engineering design by F. Cenek. Tower #2 is a 118 m tall observation tower known as Euromast. It was built in 1960 in Rotterdam, Netherlands and the architectural design was done by J. Maaskant, with structural engineering design done by A. J. Neste and R. Swart. Tower#3 is a 20 m tall, masonry water tower, designed by the Uruguayan structural engineer

Eladio Dieste in 1980. It is located in Uruguay. Tower#4 is a 29 m cast iron sculpture designed by the famous sculptor Constantin Brancusi. It was built in 1938 in Târgu Jiu, Romania. Tower#5 has yet to be built. It is known as the "Shanghai Kiss", designed by British Architect William Alsop, with structural engineering done by London's Arup office. It is to be a 250 m tall observation tower, designed to attract visitors to the World Expo 2010.

Thus, although one structure is solely the work of a sculptor (Brancusi's Tower#4), and one is solely the work of an engineer (Dieste's Tower#3), all of the forms have sculptural, architectural and structural features.

The following is the survey which nearly one thousand respondents filled out.

Figure 1. Opening Question

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1. Please tell us who you are?

- Architecture Student
- Architectural Engineering Student
- Civil Engineering Student
- High School Student
- Architecture Faculty
- Engineering Faculty
- Other (please specify)

Please look at the five towers on the following page. You will be asked to rank them according to a single criterion.

Figure 2 The Towers

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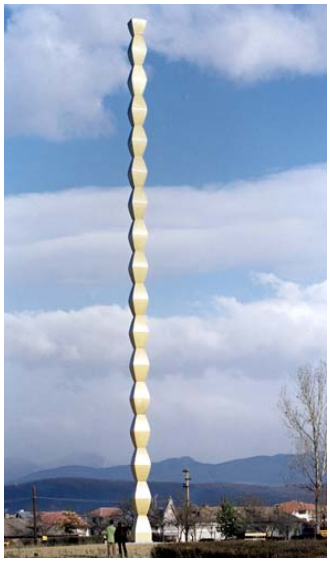
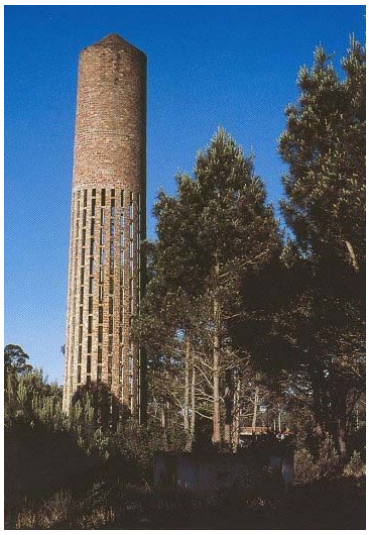


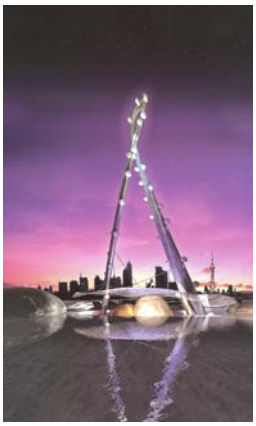
Tower #1



Tower #2

Tower #3

Tower #4



Tower #5

Figure 3. Initial Ranking

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Please rank these 1 to 5, with 1 being the most sculptural and 5 being the most structural

	1	***2***	***3***	***4***	***5***
	Sculptural		***Architectural***		***Structural***
Tower #1	☐	☐	☐	☐	☐
Tower #2	☐	☐	☐	☐	☐
Tower #3	☐	☐	☐	☐	☐
Tower #4	☐	☐	☐	☐	☐
Tower #5	☐	☐	☐	☐	☐

Figure 4. The Text Panel

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Sculptors, architects and structural engineers are all concerned with designing three dimensional forms. Yet, they create their forms according to different criteria.

Sculptors often create their sculptures before they have a client. Thus, they are free to create what appeals to them aesthetically. They always consider their creations to be works of art, and the sculpture may or may not be purchased after it is completed. If the sculpture is large, issues of structural safety and integrity must be addressed by the sculptor.

Architects design numerous forms, only some of which actually get built. For an architectural design to come to fruition, it must satisfy the client's needs as well as local building codes to ensure safety of the public. Architects work with many different people to realize their vision of a completed form. Some of these people include structural engineers, construction managers, the client, government officials and citizen review boards.

Structural engineers design many types of forms, some of which are dictated by architectural concerns such as office buildings and sports arenas. Other forms have no architectural designers, they are utilitarian and they are designed to perform their prescribed function, at a minimal cost and optimum safety levels. These may be storage tanks, chimneys, electrical utility towers and the like. Yet some structural engineers are able to combine practical utility with aesthetically pleasing forms.

Figure 5. The Two Questions on Freedom
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3. Do you think that sculptural form has more freedom or less freedom than architectural form?

More freedom

Less freedom

It depends!

4. Do you think that architectural form has more freedom or less freedom than structural form.

More freedom

Less freedom

It depends!

Please look at the towers again and rank them once again, from most sculptural to most structural.

(*Here, the same five images were shown once again in their original order*)

Figure 6. The Second Ranking
****

Please rank these 1 to 5, with 1 being the most sculptural and 5 being the most structural

	1	***2***	***3***	***4***	***5***
	Sculptural		***Architectural***		***Structural***
Tower #1	☐	☐	☐	☐	☐
Tower #2	☐	☐	☐	☐	☐
Tower #3	☐	☐	☐	☐	☐
Tower #4	☐	☐	☐	☐	☐
Tower #5	☐	☐	☐	☐	☐

Results Of The Survey

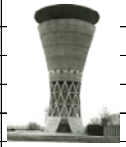
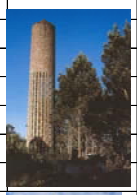
Nearly one thousand people took this survey. The technique I used to distribute this survey was to email it to all the accredited architectural engineering programs in the US (14 schools), and to approximately 12 large architecture programs and 12 large civil engineering programs. It is difficult to estimate how many people were given the opportunity to fill out the survey, but simply chose not to. But my rough estimate is that several thousand, perhaps four or five thousand people may have been offered the survey. Such a statistical sampling is known as a "convenience sample", because the survey was filled out on a voluntary basis. Those who did respond may be "different from" those who chose not to. There was no attempt made to follow up on non-respondents.

The following tables and figures summarize their responses of all participants. Further breakdown according to area of study will be shown later.

Table 1. Profile of Respondents

Architecture Student	42.4%(412)
Architectural Engr. Student	32.0%(311)
Civil Engr. Student	10.8%(105)
High School Student	6.2%(60)
Architecture Faculty	1.8%(17)
Engineering Faculty	2.1%(20)
Other (Please specify)	4.7%(46)
	Total=971
	0 skipped this question

Table 2. All Respondents First Ranking

		Sculptural	→	Architectural	→	Structural	Responses
Tower#1		4%(35)	18%(167)	40%(383)	25%(234)	13%(127)	946
Tower#2		2%(16)	8%(73)	26%(221)	36%(310)	28%(244)	864
Tower#3		2%(16)	8%(70)	27%(231)	37%(317)	27%(230)	864
Tower#4		37%(324)	38%(331)	14%(118)	6%(53)	5%(39)	865
Tower#5		66%(569)	16%(141)	9%(78)	5%(39)	5%(39)	866

It is worth noting that a large percentage (107/971) skipped this question. This is inexplicable, why would someone fill out this survey, but not answer the first substantive question?

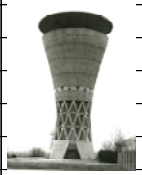
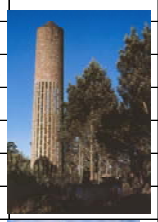
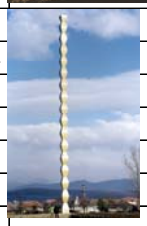
The results for all respondents' response to the questions on freedom are presented in Table 3.

Table 3. All Respondents Freedom Question

Do you think that sculptural form has more freedom or less freedom than architectural form?	
More freedom	81.6%(648)
Less freedom	8.1%(64)
It depends!	10.3%(82)
	Total=794
	177 skipped this question
Do you think that architectural form has more freedom or less freedom than structural form?	
More freedom	62.0%(497)
Less freedom	21.8%(173)
It depends!	16.7%(132)
	Total=802
	187 skipped this question

Then the respondents were asked to once again categorize the forms.

Table 4. All Respondents Second Ranking

All Respondents, 2nd ranking								
		Sculptural	→	Architectural	→	Structural	Responses	
Tower#1		4%(30)	17%(131)	40%(305)	26%(201)	12%(92)	759	
Tower#2		2%(18)	8%(58)	26%(195)	32%(243)	32%(244)	758	
Tower#3		2%(14)	7%(55)	28%(211)	38%(291)	25%(186)	757	
Tower#4		41%(311)	36%(277)	13%(99)	5%(37)	5%(35)	759	
Tower#5		63%(478)	18%(133)	11%(80)	5%(36)	4%(33)	760	
				219 skipped this question				

The first rankings are virtually identical to this second ranking, no statistical significance was found in the small differences. But one number is startlingly different, the second ranking had 219 respondents refusing to answer! If the first non-respondent rate was unfortunate, this second, quite large percentage is troubling, yet once again inexplicable.

Analysis of Answers

ALL RESPONDENTS

When viewing the entire group of respondents for either the first or the second ranking, there was fairly clear consensus on how to categorize each tower. The following is a synopsis of the first ranking, which had more respondents. Tower#1, the concrete water tower, was chosen by 40% of the respondents as an architectural form, with another 25% placing it between architectural and structural. Only 4% labeled it as sculptural.

Tower#2, the Euromast, was placed by 28% as structural, another 36% as being between structural and architectural, and 26% as architectural. Very few (10%) placed it towards the sculptural end of the continuum.

The Dieste water tower, Tower #3, was very similarly categorized. Almost all respondents (90%) placed it between somewhere on the architectural/structural side of the continuum.

Brancusi's Endless Column sculpture was "correctly" placed by 37% as sculptural and another 38% between sculptural and architectural. Very few (5%) categorized it as structural. Perhaps this is because it may have been recognized by the respondents, seeing as it is the most famous of the five towers.

Alsop's observation tower The Shanghai Kiss, was categorized by 66% as purely sculptural. One explanation for the avoidance of the architectural category may be that the image is from fairly far away, and one cannot readily see that this is an observation tower.

The answers to the "more or less" freedom had an overwhelming favorite.
82% of the respondents agreed that sculptural form has more freedom than architectural form. This corresponds to the point of the didactic text panel.

Only 62% agreed that architectural form has more freedom than structural form. Curiously, 22% disagreed. This is counter to the "advice" of the didactic panel. There may be two explanations for this. One is that the respondents understood the panel, but simply disagreed with its premise. The other explanation is that they did not understand the panel.

A chi squared statistical analysis was performed of the rankings on a tower by tower basis. The results for tower#1, the concrete water tower, are shown in the following table. The question we posed to ourselves with this statistical analysis was this; did the TYPE OF student significantly affect rankings for a given tower. If NOT, then there will be no need to look at comparisons on a Tower by Tower basis, i.e. filtering out the ARCE students view of Tower#2 for example. The results show that there is no dependence based on the type of student. This agrees with our intuitive assessment of the results, i.e. that when looking at the entire population, or looking at individual types of students, the rankings were approximately the same. This surprised us.

Table 5. Chi Squared Analysis of Tower#1 Only

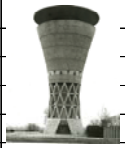
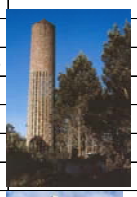
		Sculptural	Sc/Arch	Architectural	Arch/Struc	Structural	Total
Arch.	observed count	14	62	125	81	33	315
	expected count	12.67	57.90	124.50	85.10	34.90	
	chi squared contrib.	0.139	0.286	0.002	0.196	0.098	
ARCE	observed count	6	39	101	75	31	249
	expected count	10.00	45.80	98.40	67.30	27.55	
	chi squared contrib.	1.611	1.008	0.070	0.334	0.433	
Civil	observed count	2	17	36	22	8	85
	expected count	3.40	15.60	33.60	23.00	9.40	
	chi squared contrib.	0.589	0.120	0.174	0.040	0.210	
High Sch.	observed count	6	10	13	13	5	
	expected count	1.89	8.64	18.60	12.70	5.20	
	chi squared contrib.	8.930	0.213	1.671	0.007	0.008	

Chi-Sq=16.138 P-Value=0.185

Analysis of Answers ARCHITECTURE STUDENTS ONLY

Moving on to the filtered responses assessing all five towers together, we first look at the largest group, the Architecture Students only, who made up 42% of the total responses.

Table 6. Architecture Students only, First Ranking

		Sculptural	→	Architectural	→	Structural	Responses
Tower#1		5%(20)	22%(80)	32%(118)	26%(95)	14%(52)	365
Tower#2		1%(5)	8%(30)	29%(106)	37%(134)	24%(89)	364
Tower#3		2%(6)	8%(29)	30%(108)	37%(134)	24%(86)	363
Tower#4		36%(132)	38%(139)	13%(46)	7%(27)	6%(21)	365
Tower#5		65%(237)	16%(58)	9%(33)	5%(19)	5%(18)	365

As shown in the previous chi squared analysis, these results are virtually identical to the total group's response, no statistical significance was found in minute differences from overall group's responses. The agreement in fact, is quite remarkable, comparing for example the ranking of Tower#4 (the Brancusi) in Table 2 and Table 6, one sees almost identical results.

When it came to the questions about freedom, the first answer (Sculptural form vs. Architectural form) was extremely similar to the overall group response. But the question about freedom in Architectural form vs. Structural form, found slightly less unanimity than before, with the "It depends" category gathering 21% now as opposed to 17% for the total group.

Table 7. Architect Students Only, Freedoms Questions

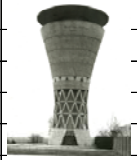
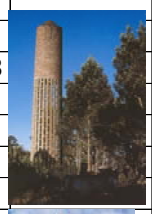
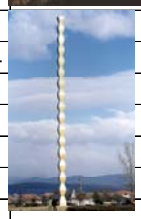
Do you think that sculptural form has more freedom or less freedom than architectural form?	
More freedom	79.7%(263)
Less freedom	5.8%(19)
It depends!	14.5%(48)
	Total=330
Do you think that architectural form has more freedom or less freedom than structural form?	
More freedom	59.0%(197)
Less freedom	20.1%(67)
It depends!	21.0%(70)
	Total=334

Analysis of Answers

ARCHITECTURAL ENGINEERING STUDENTS ONLY

The next filtered response we look at is the second largest group, the Architectural Engineering Students only, who made up 32% of the total responses. Their categorization was as follows.

Table 8. ARCE Students Only, First Ranking

		Sculptural	→	Architectural	→	Structural	Responses
Tower#1		3%(9)	17%(50)	34%(99)	30%(88)	15%(45)	291
Tower#2		2%(5)	10%(30)	22%(63)	37%(106)	29%(85)	289
Tower#3		1%(2)	7%(20)	27%(77)	34%(100)	31%(91)	290
Tower#4		36%(104)	40%(117)	14%(41)	6%(17)	3%(10)	289
Tower#5		67%(194)	15%(44)	9%(25)	6%(16)	4%(11)	290

There was no statistical significance to the small variations in categorizations of forms by the Architectural Engineering students compared to the overall group and compared to the Architecture students. Again, this is somewhat surprising. Prior to this quantifiable analysis, we surmised there might be discernable differences of rankings based on student group.

The Architectural Engineering students answered the questions about freedom as follows.

Table 9. Architectural Students Only, Freedoms Questions

Do you think that sculptural form has more freedom or less freedom than architectural form?	
More freedom	84.5%(223)
Less freedom	8.3%(22)
It depends!	7.2%(19)
	Total=264
Do you think that architectural form has more freedom or less freedom than structural form?	
More freedom	70.4%(188)
Less freedom	17.2%(46)
It depends!	12.4%(33)
	Total=267

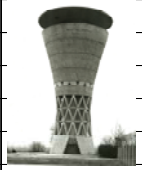
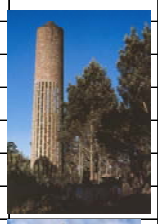
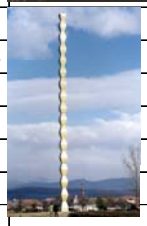
The Architectural Engineering students slightly more unanimously on the question of sculptural form having more freedom than architectural form (ARCE 85% vs. 82% for the entire group and 80% for Architecture). But on the question of freedom of architectural form versus structural form, the Architectural Engineering students had significantly more unanimity than both the overall group and the Architecture students (70% ARCE versus 62% for the entire group and 59% for the Architecture students). A reason for this may be that the Architectural Engineering students are naturally more aware of and interested in structural form, and they are particularly attuned to the difference between structural design and architectural design.

Analysis of Answers

CIVIL ENGINEERING STUDENTS ONLY

The next filtered response we look at is the third largest group, the Civil Engineering Students only, who made up 11% of the total responses. Their categorization was as follows.

Table 10. Civil Students Only, First Ranking

		Sculptural	→	Architectural	→	Structural	Responses	
Tower#1		2%(2)	21%(20)	39%(37)	29%(27)	9%(8)	94	
Tower#2		0%(0)	5%(5)	21%(20)	40%(38)	33%(31)	94	
Tower#3		2%(2)	3%(3)	19%(18)	46%(43)	30%(28)	94	
Tower#4		35%(33)	45%(42)	15%(14)	4%(4)	1%(1)	94	
Tower#5		64%(60)	22%(21)	9%(8)	2%(2)	3%(3)	94	

The categorizations of the Civil Engineering students generally agreed with the other groups' categorizations, with only slight variations in some of the answers. For example, the Civil Engineering students had slightly less scatter with Tower#3, The Dieste Concrete Water Tower, tending to group it more solidly in the structure category, with only 19% vote in the Architecture slot (ARCH voted 30% and ARCEs put 27% for Tower#4 as architecture). This difference was may be attributed to the fact the Civil Engineering students may be more aware of the role and the design of water towers.

With regard to the question on freedom, the Civil Engineering students voted nearly the same as the overall group on the first question. And as with did Architectural Engineering students, the Civil Students had more unanimity on the question about structural form versus architectural form than did the Architecture students. 73% of Civils said architectural form has more freedom than structural form, compared to 62% for the entire group, 59% for Architecture students and 70% for ARCEs).

Table 11. Civil Students Only, Freedoms Questions

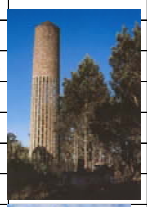
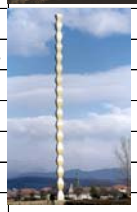
Do you think that sculptural form has more freedom or less freedom than architectural form?	
More freedom	81.8%(72)
Less freedom	13.6%(12)
It depends!	4.5%(4)
	Total=88
Do you think that architectural form has more freedom or less freedom than structural form?	
More freedom	72.7%(64)
Less freedom	18.2%(16)
It depends!	9.1%(8)
	Total=88

Analysis of Answers

HIGH SCHOOL STUDENTS ONLY

The last filtered response we look at is the fourth largest group, the High School Students who made up only 6% of the total responses. While this is a small group, it is still interesting to look at their responses, with the caveat that it is not a large data set. However, our statistical analysis showed that the number of High School students respondents barely qualifies it as a viable respondent group.

Table 12. High School Students Only, First Ranking

		Sculptural	→	Architectural	→	Structural	Responses	
Tower#1		6%(3)	16%(8)	39%(19)	20%(10)	18%(9)	49	
Tower#2		8%(4)	8%(4)	27%(13)	24%(12)	33%(16)	49	
Tower#3		10%(5)	18%(9)	22%(11)	27%(13)	22%(11)	49	
Tower#4		40%(21)	27%(14)	15%(8)	6%(3)	12%(6)	52	
Tower#5		67%(33)	12%(6)	12%(6)	2%(1)	6%(3)	49	

Although it is dangerous to draw too many conclusions from this smallest set, one difference in categorizations is immediately evident. The High School students had greater unanimity in the placement of the Brancusi sculpture (Tower#4) in the category of Sculptural form. This "correct" answer was detected most by the High School students with 40%. The other categorizations show no large variations from the overall group. For example, the High School students had almost exactly the same rankings for Tower#5 (Alsop's Shanghai Kiss) as did the Architectural Engineering students.

The second question on freedom was answered differently by the high school students, than by the overall group. The high school students disagreed with the overall group and with the other sub groups on the question of freedoms between architectural form and structural form. They voted that architectural form actually has less freedom than structural form, whereas the others answered the question "correctly" in accordance with the didactic text panel. Perhaps the high school students did not understand the brief panel presenting the concept of restraints and freedom.

Table 12. High School Students Only, Freedoms Questions

Do you think that sculptural form has more freedom or less freedom than architectural form?										
More freedom								78.7%(37)		
Less freedom								19.1%(9)		
										0.0%
It depends!								2.1%(1)		0.0%
								Total=47		0.0%
Do you think that architectural form has more freedom or less freedom than structural form?										
More freedom								37.5%(18)		
Less freedom								56.3%(27)		
										0.0%
It depends!								6.3%(3)		0.0%
										0.0%
								Total=48		

Conclusions

When faced with a clear continuum of forms, from sculptural through architectural to structural, students tended to categorize forms consistently. Whether the student was studying architecture, architectural engineering, civil engineering, or was in high school, the categorizations were essentially the same. In fact, it was surprising just how similar the rankings were from student group to group.

We argue that this continuum of form is helpful when discussing three dimensional designs. Other authors have discussed particular aspects of one form or another, but our literature review did not find anyone who succinctly put all three types of form on one continuum, linked through increasing scientific constraints. The common thread of increasing scientific concerns imposed on the designer, as one moves from sculptural form, through architectural form to structural form, is helpful to those who want to discuss and critique large three dimensional forms.

References

(1) Billington, D.P. (1983) *The Tower and the Bridge*, Basic Books Inc.Publishers, New York, N.Y. p. 17.

(2) Kepes, Gyorgy (editor). 1965. *Structure in Art and Science*, George Braziller Inc., New York, N.Y. p. 150.

(3) Saliklis, E.P, Bauer, M. and Billington, E.S. (2006) "Simplicity, Scale and Surprise: Evaluating Structural Form", Accepted and scheduled for publication in the American Society of Civil Engineering's Journal of Architectural Engineering.

(4) Howard, H.S. (1966) *Structure: An Architect's Approach,* McGraw-Hill, Inc., New York, N.Y. p. 15 and p. 17.

(5) Jencks, C. (2005) *The Iconic Building*, Rizzoli International Publications, Inc., New York, N.Y. p. 132 and p.40.

(6) Sudjic, D. (2005) *The Edifice Complex: How the Rich and Powerful Shape the World*, The Penguin Press, New York, N.Y., p. 11.

(7) Rybczynski, W. (2006) "Failed Icons: Why it's so hard to make unforgettable architecture", posted Wednesday, August 9th at 11:59 AM ET on slate.com

(8) Charleson, A. (2005) *Structure as Architecture*, Elsevier Architectural Press, Oxford, England. p. 20.

(9) Thornton, C. and Tomasetti, R. (editors) (1993) *Exposed Structure in Building Design*, McGraw-Hill.

(10) Nervi, P.L. (1965). *Aesthetics and Technology in Building*, Harvard University Press, Cambridge, MA. p. 4.

(11) Khan, F.R. (1981). "Structural Theories and their Architectural Expression – A Review of Possibilities." The Chicago Architectural Journal, Vol. 1, p 41.