

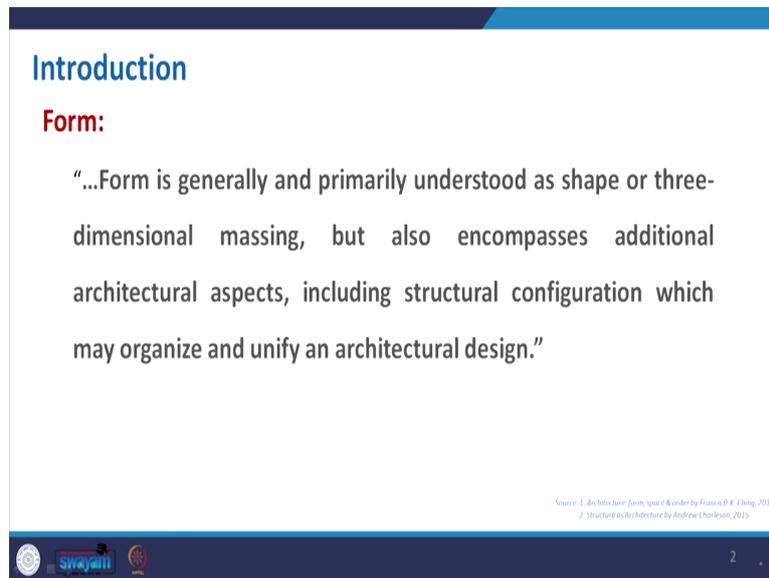
Structure, Form, and Architecture: The Synergy
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Lecture - 05
Synthesis of Architectural and Structural Form

Hello friends, welcome back to online course Structure, Form and Architecture: The Synergy. Today, we will talk about lecture number 5 that is Synthesis of Architectural and Structural Form. So, before I start today's lecture so far whatever we have covered we have seen that structural form, they helped to make architecture, to fulfill the concept and also bring some architectural visual qualities and also we discussed different kind of loads in our previous lectures, where we have seen like starting from the dead load, live load, then different lateral loads, seismic load etcetera.

So, in this lecture, we will basically focus on different structural form and how they are making you know strong correlation with architectural form creation. So, we will pick up some of the major and predominant structural form that being used to create some world class architecture and in the modern world. So, gradually, we will also say like take some examples from the history, where other kind of structural form being created to bring the architecture.

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Introduction

Form:

“...Form is generally and primarily understood as shape or three-dimensional massing, but also encompasses additional architectural aspects, including structural configuration which may organize and unify an architectural design.”

Source: 1. Architecture: Form, Space & Order by Francis D.K. Ching, 2015
2. Structure as Architecture by Andrew Charkton, 2015

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So, let us start to this lecture. Here, we again like previous lectures we just looking to the definition. So, what is a form already we have discussed it. The form is basically the visible object and we define it with a shape. So, it is a definition given by Francis D K Ching. So, what exactly it is let us have a look into this. Form is generally and primarily understood as shape or three-dimensional massing ok.

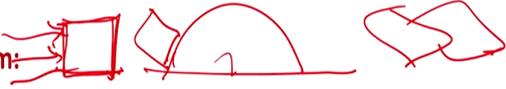
So, one object having three dimension that will give a sensation to our eyes and we see that object as a form. But also encompasses additional architectural aspect. So, its not like very dull three-dimensional shape, but in order to make it and give a you know term called architectural form. So, it also have different aspect like space creation, then different arrangements including structural configuration and this is obvious after you know initial few lectures.

Now, we all agree that in order to give the form of architecture structure is indispensable, means it is very much needed without structural stability, structural support, it cannot create the form the way, we want which may organize and unify architectural design. So, basically form by this definition if we simplify this. So, it is three-dimensional object along with that it will have some architectural aspect. It should have some space to live in order to you know maximize your utility. And, also this should be supported with some structural configuration.

And finally, altogether it will basically create and unify an architectural design. So, with that we move forward to the architectural form.

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Introduction

Architectural Form: 

“...architectural form is an inclusive term that refers primarily to a building’s external outline or shape, and to a lesser degree references its internal organization and unifying principles...”

-Francis D.K. Ching

Shape encompasses various **visual and relational** properties:

SIZE, COLOUR, TEXTURE, POSITION, ORIENTATION and VISUAL INERTIA

Source: Architecture form, space & order by Francis D.K. Ching, 2015

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So, here it says Architectural form is an inclusive term that refers preliminary to a building external outline. Here this is very important external outline or shape. So, whatever the form we normally say, so basically most commonly we referred to the outline of the building if a

building is something like that. So, we say it is a domical form of a architecture. What is inside the space essentially we do not say about that and to a lesser degree reference is internal organization, as already I mentioned like in order to create architecture, we have to articulate spaces.

So, it will have a relationship between different space, their transitional space, how we connect to space. So, that is very important for creating good architecture so that our purpose to create will be achieved. But when we discussed about the form, so basically it is whatever the overall shape being created and basically the outline. But sometimes also we also observed the internal form; sometimes we I have given one example of pantheon, where it is looking very beautiful from the inside that your domical form that we have seen.

So, one thing is very clear. It is giving a shape or outline. Now, in this shape is basically creating a visual representation and that also having some property of the size, color, texture, position, orientation and visual inertia. So, these all are very important thing like whether my structure will be in human skill or in monumental skill.

So, in I guess that in like who have studied the history of architecture. So, earlier we have seen that like many examples which the architecture is in monumental skill, the huge structure. So, size is something very huge and sometimes it is nowadays with the age of you know you know shortage of space and all sometimes we actually optimize the space so, which the minimalistic form and small size.

Now, to the color, definitely it will give a contrast to the background. So, whenever we see any image or over like having like some interesting photography, they also capture a frame. So, in the frame we have a background and one foreground and with different color, the contrast created. So, sometimes the architectural form is very simple rectilinear, but the color used through the material or may be paint can create something different.

Textures; obviously, we have discussed that sometimes it may be rough; sometimes it may be very smooth like glass. So, this is important in the position of that now based on the position; how you place your form one after another how you make composition, that will actually give

you a different sense. Orientation, it is again very important not only for the ecstatic purpose; but also sometimes in order to tackle with the lateral load. If you can recall the wind load that we have seen that when we place you know this recliner form and this is a prevailing wind direction. So, this create thrust. In order to that if I just rotate a bit, so we can minimize it in that.

And visual inertia is very important that will give a visual sense of stability. We have seen some of the buildings in our previous lectures that where we have seen that the building is following the stability, visual stability is there and sometimes it is not. So, it refers to the instability, visual instability to that. So, these are the properties of a firm that will make one architecture from other.

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Introduction

Structural Form: *3D*

“...the primary or most visually dominant structural system of a building...” *Handwritten red lines underline the text and circle the word 'system'.*

- A buildings may have more than one structural systems: which system is visually dominant? *Handwritten red lines underline 'more than one structural systems' and 'dominant?'.*
- Concept of Structural Form is unhelpfully simplistic *Handwritten red lines underline 'Structural Form' and 'unhelpfully simplistic'.*
- The term Structural Systems is more appropriate *Handwritten red lines underline 'Structural Systems'.*

Comprehensive Template

Source: Structure as Architecture by Andrew Chapple, 2015

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Now, come to the structural form. So, form is shape now how to do really distinguish between architectural form and structural form that is a question. So, here structural form is the primary or most visually dominant structural system of a building ok. This statement is not really giving a very comprehensive answer to us. So, what exactly one two mean?

So, so far we discussed that the shape is the three dimensional thing then, in order to make it architectural form. So, it should have some you know some space and other thing to call it architecture and then, basically architecture is the outline of that architectural design. This shape, this outline is your architectural form whether it is in rectilinear form or in it sub curvature something.

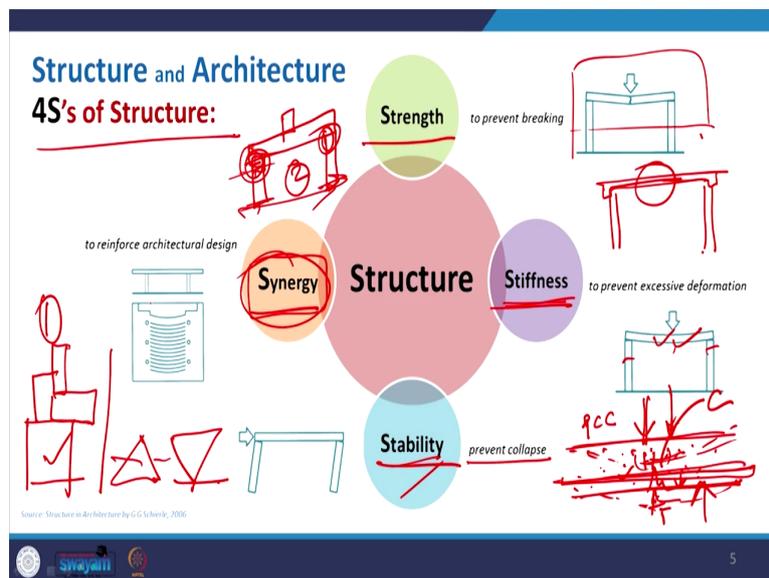
Now, structure is basically the backbone of the dominant structural system. Now, here we should be careful. So, when we say the dominant structure, what exactly like by looking at the building, you will just get to know that this structure system is of this kind; but sometimes even rather most of the cases a building may have more than one structural system, one two just give the structure stability, other may to give some you know other facility facilities. So, which system is visually dominant that is a question.

So, which form will take a building may have a arch form, some part of the building and somewhere it is just a you know beam column structure. So, there which form should we take. So, concept of structural form is unhelpfully simplistic. So, basically when we say structural form, its rather to say this is the structural system. So, when we say structural systems, then we have some category in to that.

So, we can classify our structural system in many ways; so, one way of classifying it with the overall shape of three-dimensional shape and other thing. But structure system can also be defined with other parameters like its nature whether it is like your compressive structure or it is your tensile structure or so on or else, we can also define it in other terms like your supporting structure or supported structure. But in this particular lecture, will not discuss those; will come to that in some you know future lectures. But in this preliminary, we will focus on the structural form based system.

So, I will just make it clear with certain example. Say for example, if you see a building making of such you know concrete or steel member and the form being created is simplifying or simply say it is an arch. So, this is basically the form, but again this system whether it is like your tensile or it is compressive or something will touch up on those issues and we will discuss one by one in our future lectures.

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So, let us move on to the concept. Again, this is very important and very interesting slide. So, here the structure can be defined with 4S's: Strength, Stiffness, Stability and Synergy. So, what is strength? So, basically strength is some property by which you can prevent breaking ok.

So, if I having a beam which is having good strength, may be made of good quality concrete; so, it will resist more load. So, it will stop from breaking, but at the same time say for

example, I take this pen examples. So, it is made of some material having, some kind of strength; but not as compared to concrete. So, if I put pressure on that it may break.

With pen, it may take some time; but if you do it with a chalk maybe as because of his you know brittle property, it will break even you know earlier than this one. So, strength is very important do you like property of a structure. So, depending on the load, also we have to you know we choosy about selecting material having the proper strength which will help to prevent from the breaking. You can see this you know schematic, where this is a beam and supported by two columns and when a load is applied showing by this arrow. So, it is breaking.

So, if you make it strong, then it will. But regarding this I just want to highlight another important issue will also come to that later on. But as because now we are discussing this say for example, we make a slab resting on a column. So, basically if you know this is particular section. Now, in this case I just zoom it. So, suppose this is made of concrete and made of PCC. PCC stand for Plain Cement Concrete. So, there is no reinforcement. Now, because of the self weight and also some live load; load of furniture and then, people. So, it will have some bending.

And what is happening here? So, if you want to see this one this section. So, the upper portion will have one type of load that is like they will have the compression ok. So, this particular portion will try to you know contracting to each other and this portion will try to expand. So, tension will be developed here.

Now, for that reason, it will collapse from the bottom. In this case because load is applied from the top if I apply load from the bottom. So, it will first develop crack in the upper section and let me tell you one thing that like concrete like plain cement concrete. So, basically the property of concrete, it is having good compressive strength. So, in compression, it will sustain. But not intentional, but tension developed at the bottom.

So, in order to overcome we have to support it we have to reinforce it with some material having higher intentional strength value and that is why we put reinforcement and the reason

for this kind of slab, we put the reinforcement in the lower side of the section ok; so, that this will take care of the tension.

So, it will give a balance with tension compression and finally, will have some equilibrium. So, we will come to that and we will discuss with some experiment also, but anyway. So, to make it sometime stronger having good strength, we may look for some combination of different structural material.

Now, come to stiffness; stiffness is the property which will prevent the excessive deformation. Say for example, if it will not have this much of stiffness. So, it will deform and the time like if you create some structure having higher deformation which will not be really a good sign because then, your whole structure the you know the supporting structure the supported structure on this column may act in a different manner. So, this is another property which is very important to select about the structure.

Now, come to stability; stability will depend on the arrangement of your structural element. We have given one example like your pyramid and inverted pyramid ok. So, depending on the arrangement because of the lateral load and other thing; so, stability is basically you know prevent the collapse. So, if arrangement is something like that we make a composition; something like this is one, option number 1 and I just make option number 2 here ok. So, when we arrange this you know cuboid one after another. So, this is option number 1; this is option number 2.

Now, my question to you looking at these two and consider the same material and all which structure is considered to be more stable? So, I am sure that all of you agree that one is much more stable than two because of the mass and other thing and that is why those points, where it get connected is very crucial. Now, we have discussed the you know activity during earthquake. So, there will be some lateral movement in both the direction, horizontal direction, left-right and you know upward-downward.

So, in that case basically those joints are very critical because here you just represent it in the real case. So, this is slab and this is a beam or there will be some column and also those joints

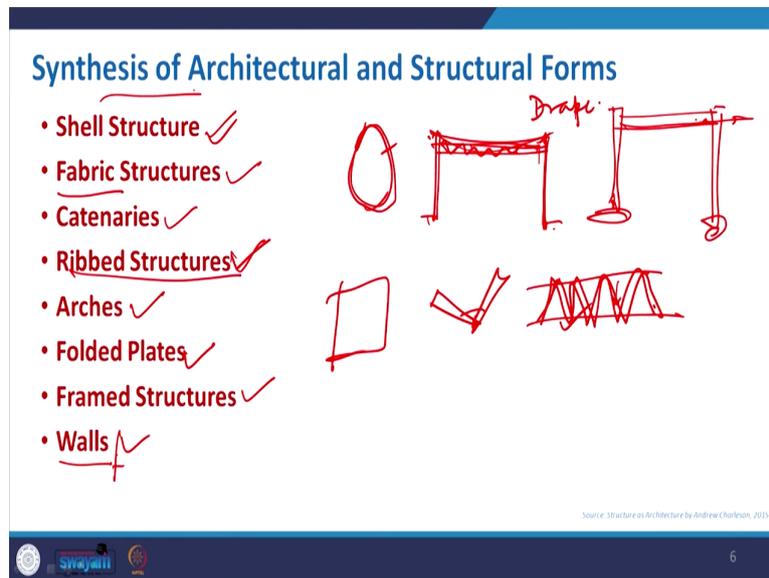
will be crusted adequately proper care should be taken so that during that movement this structure will act as a monolithic structure; what is monolithic structure? Made of say you know say similar one you know single materials. Sometime you know the cave we consider the rock card cave when all their monolithic structure; so, that all will have the motion. So, that this building will be stable

But though we have good strength material having the stiffness, the property and also the arrangement and assured the stability, but then also there is something which is very important to bring the result as per our requirement that is the synergy and that the all subject the whole course is all about the synergy between different structural element.

So, if you want something to be very strong, stiff and also stable. So, you must have a good synergy between those materials along with the design elements; so, that we cannot compromise our requirement. At the same time, we should not compromise the structure safety. So, that my structure will be basally pleasant, structurally strong and having a good durability, it will stay for longer.

So, this is something is very important and looking into this concepts, sometimes you know we have to reject some of the structural form which may not be applicable for our design. So, in upcoming slides what will see basically the synthesis between architectural form and structural form. So, looking at that basically it will give a sense of a shape three-dimensional shape, but at the same time it is being so well-designed, its giving the architecture, the way we want and also the structural form that support that to bring it into reality. So, let us move forward.

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So, here we have listed 8 such you know structural and architectural form synthesis and we will see by with some examples, some photographs from you know different parts of the world and specially the modern architecture. So, one is your Shell Structure; second one is Fabric Structure; Catenaries is one of them; then you have Ribbed Structure, then Arches, Folded Plate, Framed structure and Walls. These list can be further extend it and will also do that and will discuss some other kind of structural like pneumatic structures and other form of you know shape that we use and structural element we use in architecture.

But before, we again proceed further; let us understand by the term what is shell. So, basically I can give you example of egg. So, what exactly it is the white outer shell is having enough strength and in the some of the experiment is a it has been shown that it may take up to even more than 20 to 22 kgs load. So, this is very thin very thin; it is so brittle and you know who

are having eggs in their daily menu and all they know that when you break it for the omelet or something. So, it is very thin, but it is able to carry certain load.

So, this thin shell will make your space precious, at the same time it can also take the load. So, what is the property basically? So, the it will reaches the load external load and shell for it through its thickness and proper geometry, that is very important. You know in order to achieve the result we should also look into the geometry, how the curvature to be drawn for the shell structure and all and we will get some example to that. Fabric is basically something related to the cloth or membrane kind of material.

So, sometimes in order to make structure very light, we use this kind of structure and you know already I have given one example of stadium, unique stadium, where we have seen the huge structure. Though there example was taken for a light weight type structure, but here we can take the same example, where like with some you know steel members and all the whole area is been shredded with some translucent you know fabric and there is so many application of this fabric where it is basically act with a tension.

So, the tension tensioned fabric to be supported with some cables and yeah; obviously, there will be some support which will help to balance that and some comprehensive element structure to be fixed, where this membrane or the fabric at tied up. Then, catenaries is basically a form that we normally see that it is basically a member which is you know drape, means it is simply you can say hang on this two pole.

So, if you see the railway track over that all those you know electric poles and this transmission you know cable and other thing. So, we have some portal kind of structures. So, this is a catenaries structure. I can give you another example. We also call it catenaries that is the queue you know in station or in some of them meeting place in order to manage the queue, we have certain poles like this and there is some elastic material which may be you know free stand in any direction. So, this is also called catenaries.

So, we will see this application in our architecture. Then, ribbed is something like the skeleton ok. So, if you remember we started with the lecture, where we have seen like take

example from the nature like the human body; though we have some muscles, we have some outer finish and with some clothing and all we take it in a different manners. So, depending on the color and other thing, but basically we are stable or we are standing because of some support of the bone the skeleton. So, as too for some structure where, it is very much predominant ok.

So, every building, they must have some you know structure or you know skeleton, but this kind of ribbed structure is very predominant. We will look into that also. Then arches are very simple. So, different kind of arches may form the architecture. Folded plate, I explained with some paper right.

So, if you have a paper and then, if you just fold it ok so, it may carry some load and when you make it in order. So, it can also take a huge load on it and why it is taking load and all; how it will balance the comprehension and tension, we will discuss in detail when we discuss about the folded plate structures separately in the class. So, here we will see like some examples under this category. The framed structure is very simple, straight forward, beam column composition structure.

So, this is something normally we see in house or something it has been practiced from. So, long then the walls. Sometime you know we have also shown some example, where you have very you know opaque type of you know quality in your structure where you have some you know very less opening or no opening and walls are predominant to it. So, the walls some arrangement of walls will create some architecture.

So, let us move to each of these category and take some examples and try to understand clear what exactly how this synthesis is happening with architecture and structural form.

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Synthesis of Architectural and Structural Forms

Shell Structure



- Also known as 'Surface Structures'
- Shells resist and transfer loads within their minimal thicknesses
- Needs two- or three-dimensional curved geometry and correct orientation and placement of supports

Bus Station Casar de Cáceres
Cáceres, Spain

Source: <https://www.archdaily.com/bus-station-casar-de-caceres-josua-garcia-rubio/>

Source: Structure as Architecture by Andrew Charkson, 2015

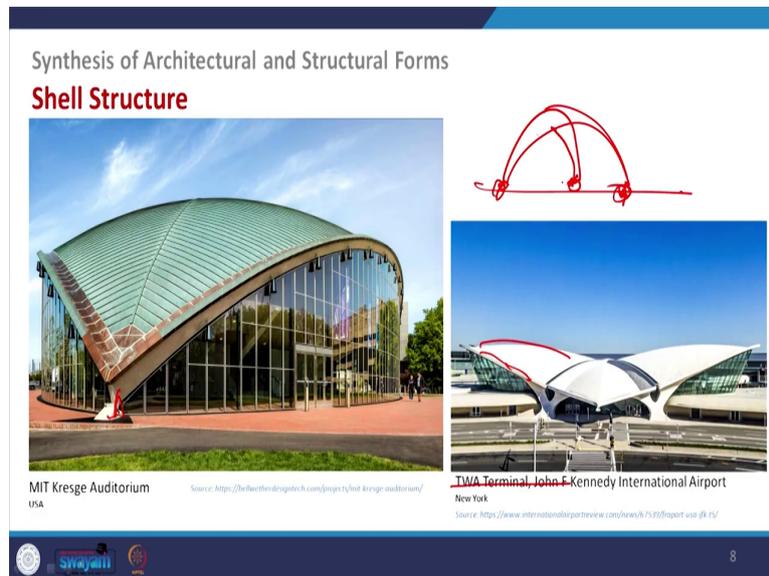
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This is one example and this is very simple one a small one like the bus station ok. A shelter, you can see this is may be the office area like official thing and all and people can wait there. This is the bus. So, here you can see the thickness ok, very thin and this is giving a form of an arch. So, it is also known as surface structure. Because as of the thickness shells resist and transfer the load within the minimal thickness and that is the advantage of using it. The similar shell structure being used in Sydney Opera House even in or you know lotus temple in Delhi, from India.

Now, for that what is required two or three dimensional curved geometry and correct orientation. So, to give the support where to support it, where it should be oriented, how it will counter the weight transfer the weight that is very important in this shell structure. And what is the advantage if you see this, so this area is having no column. So, you can create

some kind of interesting space, column free space wherever we require it. So, this is one example very beautiful example on shell structure.

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Here, we take another two this is one auditorium in MIT and this is already sometimes back, we have given this example of the TWA Terminal and that time, we have taken this example as a like form like flying bird or something. But here, we are taking its structural element which is very thin made of concrete; so, creating the shell structure.

So, they have been supported somewhere and it can be created. So, basically the shell structure if you just design it ok, with a proper geometry making or the balance take care of the moment of inertia. So, you can create beautiful space with this and the material sometimes it may be or made of concrete, sometimes you can also think of some other material without compromising that you know your strength, then stiffness and other things and definitely the

proper orientation and positioning of the support will give the stability to give you the synergy.

So, this 4S's I have explained here how to get it. Now, come to the fabric structure. So, again it is a cloth some like material made of some you know poly ethylene based material sometime high density poly ethylene.

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Synthesis of Architectural and Structural Forms

Fabric Structure



- Tensioned fabric resists self-weight and wind loads
- Relies upon three-dimensional curvature for structural adequacy
- Requires compression members to stretch the fabric



Wolfgang Meyer Sport Centre Hamburg-Stellingen
Germany

Source: <https://www.stp.de/en/projects/wolfgang-meyer-sport-centre-hamburg-stellingen/>

Source: Structures in Architecture by Andrew Chilleson, 2013

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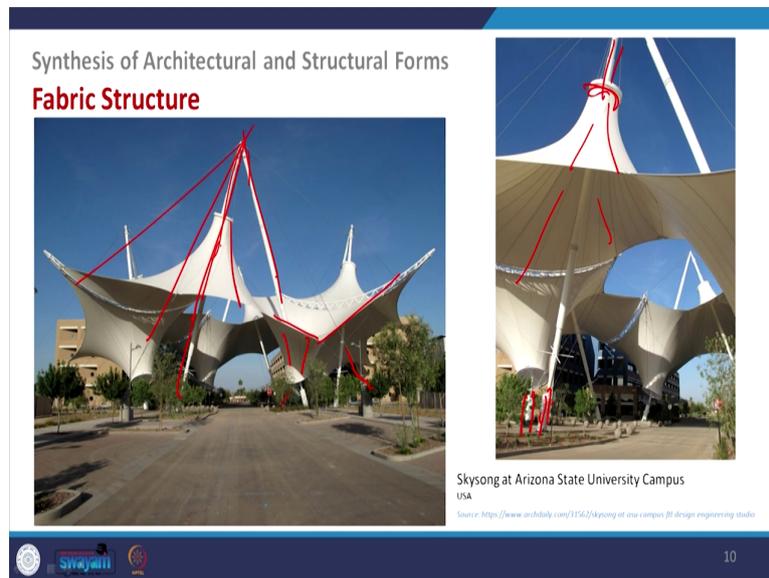
So, different kind of material to be used in this and these are being very useful to create your you know reduce the load of the roof, where it is just a requirement to you know cover up the area, just to protect from the rain and the you know excessive light or heat. Then, we can propose this kind of structure.

So, we have seen one example form unique that is the stadium and here, it is ice skating ring and this is basically a sport center in Germany, where it has been used. So, you can see that how it is being placed. So, there are some supports and where this membrane is fixed and from inside also, there are some poles and there are some cables which will connect it.

So, it is the tension fabric that resist the self weight and wind load. Because you know for the wind load there is a problem of upliftment of the structure. So, if you have a pitch roof. So, there will be some you know wind, so this will create some pressure here and that can make some upliftment of structures. We have to take care of this and now looking at the form, so when we discuss this fabric or membrane structure in you know in detail you know in detail; so, there will see the different kind of you know membrane structure.

So, here it is basically a conical one and depending on that will also discuss about some you know property of the curve whether it will take the arch form or parabolic or hyperbolic form. So, will discuss this and here it is very beautifully designed, it will all take care of the tension as well as the light. So, through this one may have the light and you can see this you know people are enjoying the skating there. So, this is one application of the fabric structure.

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So, let us move on to the next. It is in again in Arizona State University Campus. So, this is a structure, it is more clear than the previous one, where like different post are being used and cables are used to provide the adequate tension to the fabric.

So, it is creating very interesting you know shade and shadow and also some space to enjoy though it is very open in nature, but this is creating beautiful piece of architecture if you see from there. So, these are all you know tensioned fabric and supported by some you know very you know lesser thickness cable, though they are having the strength to carry this thing and you have some support, long pole to tie up to create that tension in adequate manner.

So, there also we I can mention something about the cable suspended regions. So, there are many examples in the world. So, that also act with certain principle, but here it is called fabric structure because of this fabric being used in this. So, it is again having the tension tensile

structure in nature. There are some members which will take care of the compression, but overall it is another fabric structure.

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Synthesis of Architectural and Structural Forms

Catenaries



Inclined piers support the catenary slab



- Transfer loads to their supports through tension
- Roof self-weight should exceeds the wind suction or uplift pressures
- Reinforced concrete is sometimes chosen as a catenary material

Dulles Airport, Washington DC
USA

Source: Structure as Architecture by Andrew Charkson, 2015

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Now, move to the catenaries; already we have discussed that there will be some two poles and a member is just wasting on that and it is giving a form of a portal. So, here this is the example of Dulles Airport, Washington DC. So, here you can see like this is a terminal building as because you terminal building should have some you know openness and you should not really obstruct it with regular number of columns and all.

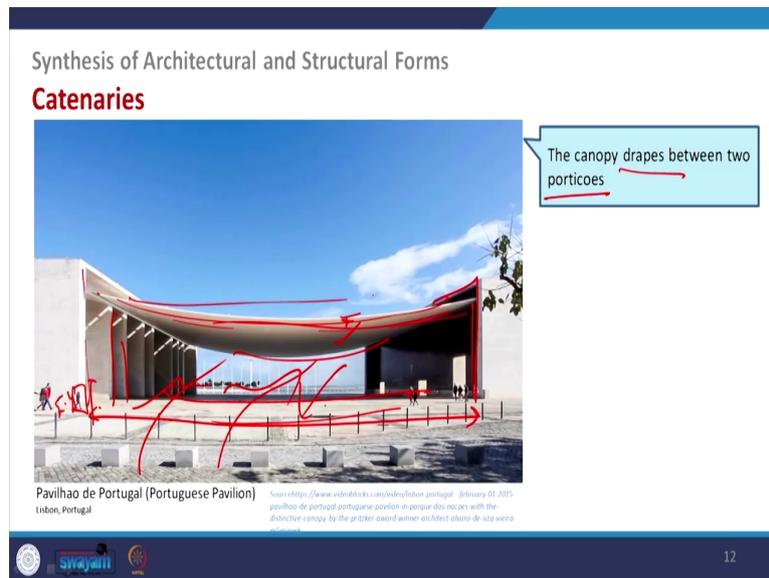
So, here you can see that this is basically a series of such component being placed one after another and then, there are some you know slabs. The catenaries which will raised on this to support ok. So, inclined piers support the catenary slab. So, this kind of structure is being seen in many cases. So, here the synthesis happened with the catenary with this. So, overall

this is giving a sense of a portal, but as well as it will also create this particular space column free.

So, whenever we require this column free kind of structure, we may think of that. So, what exactly happen there? Transfer load to the support through tension ok, roof self weight should exceed the wind load because of this kind of long span there will be if this free. So, there will be a flow of wind and other thing. So, this should have the self weight adequately so that it will resist again the wind load.

Now, reinforced concrete is sometimes chosen as the material because of the property and again, you mention look into this is RCC. As because this will act with tension, so compression can well take on by plane concrete; but in order to take care of the tension, we need some reinforcement as RCC does and compared to the other example, the Dulles airport. This is again huge.

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So, if you see this particular you know material having the thickness is very small and here what is happening? This is example of you know Pavilion Portugal. So, here these two buildings and their porticoes being connected with this canopy. So, here canopy drapes between two porticoes and it is again obtain. So, there will be you know wind blow and other thing and next with there is some water bodies also it is predominant. So, it should have the property to resist again there. So, it is allowed beam to this.

So, sometimes this kind of structure is being created to give something like some openness to that you know span and considering the scale and you consider this human being height. So, take standard height of 5 feet 4 inches. So, you can see the span is a huge span. So, it is possible it is stable, it is standing there and this huge span is being supported on and on this portico. So, this is again another example of catenaries.

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Synthesis of Architectural and Structural Forms

Ribbed Structures



- Generate and define architectural form, although their skeletal character often necessitates a separate enveloping system
- Ribbed structures generally enclose single volumes, rather than multi-storey construction

The Reichstag Cupola
Berlin, Germany

Source: <https://www.reichstag.de/reichstag-germany-parliament-photos/pictures/>

Source: Structure as Architecture by Andrew Charkson, 2015

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Now, from catenaries, we moved to ribbed structure already. The way I define that it is basically very visible that skeletons. So, here you can see look into the building. So, most predominant even this is the glass being used in this, but here if you see that there are some ring kind of structure and being supported with some ribs.

So, basically if you see this thing and we compared it with our globe. So, the latitude longitude, this is making a basically a skeleton to it and it is very well designed and here it is not in a circular form. The inside structure is basically creating a ramp which will go up. So, this is another example where the structure is basically made of steel and it is visible.

So, predominant structure as we define the structural forms sometimes is basically the predominant structural element to the building. Here it is very clear from the picture that it is the combination of ribs and like your circular the horizontal and vertical ribs to create this rib

structure. So, where it is being useful? Like it depends on the concept how we want to show sometimes you may hide your structure within the building, you can only see the overall outcome or the form of the building or if you require to show the structural element, make it very open type. So, you can do it.

So, even if you recall the example of Bangkok airport, there also something like that. So, they have multiple series of you know this kind of arch form and they connect it so that while sitting here you can see outside. So, from outside it can form this. So, the same example can be categorized at the open type of architecture in visually openness is there, but in terms of the structural thing, it is basically the ribbed structure.

Now, what exactly it is? Here there are few points that generate and define architectural form although their skeletal character often necessitate a separate enveloping system. So, what exactly it is? Like to make it; so, it may have a separate system to you know to hold it to make it stable. So, which sometimes may be very pleasant, but sometimes you just do not want it, just some portion of that is of that kind. So, you want to show it or not it depends on the architecture; but in order to give the completeness, in order to you know get that particular clarity, so its sometimes creates its own structural envelope.

Ribbed structure, generally enclose single volume rather than multi storey construction. So, whenever you have multi storey building. So, sometimes we just compromise it. So, we will simply go for a you know small kind of structure, not the high rise with the skeleton; but yeah, definitely in some of the high rise building we have used that with the ribbed structural form and we put it in grid; grid structure and all we will discuss that in the upcoming lectures. Take another example. This is National Art Center in Tokyo, Japan.

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Synthesis of Architectural and Structural Forms

Ribbed Structures



Vertical but curved ribs support and define the undulating facade



National Art Centre
Tokyo, Japan

Source: <https://www.e-architect.com/kyokujinational-art-center-tokyo>

swayam

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And here, it is another example where you see that you have some vertical membrane structures and you have some wavy structure connecting. So, from inside also if you see the openness is maintained, but it is giving ribbed like a skeleton kind of you know appearance from outside. So, it is very predominant to the building. So, I have taken this example under this category. So, vertical, but curved ribbed support and define the undulating facade. So, here it is creating some undulating effect through the structural arrangement.

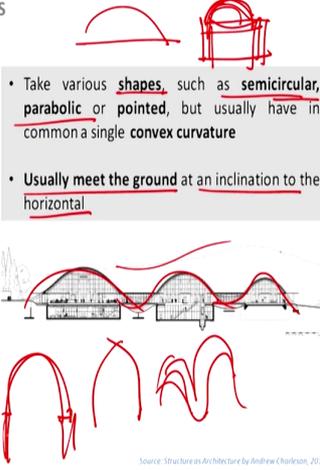
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Synthesis of Architectural and Structural Forms

Arches



- Take various shapes, such as semicircular, parabolic or pointed, but usually have in common a single convex curvature
- Usually meet the ground at an inclination to the horizontal



Paul Klee Museum
Bern, Switzerland

Source: <https://www.archipalmet.com/switzerland/bern/structures/cestrum-paul-kllee/000107/000107/000107>

Source: Structure as Architecture by Andrew Charkson, 2015

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Now, come to arches. This is another beautiful example of a museum called Klee museum in Switzerland, where beautiful use of arches and different size and all it resembles with the mountain at the back; so, to bring that you know compatibility with the environment arch being used.

So, basically take this arch form can take various shape, it may be semicircular, it may be parabolic or pointed. So, in Islamic architecture we have seen some pointed arches and sometimes in later the Felix candelas design that we have seen this kind of you know structure, where it is basically your parabolic or hyperbolic paraboloid structures and semicircle as very common.

In many of the you know domes we seen in India history, so there we use a semicircular thing even in you know Gol Gumbaz in South India. So, there also we have seen that domical

structure and usually meet the ground at an inclination to the horizontal. So, here it is meeting the ground, but sometimes when it is a combination that you have rectangle you know recliner form and then, on top of this arches or something in a domical form the section being used.

So, here basically what we are talking about the example I have given about Gol Gumbaz that is not exactly the arch, that is the dome. So, here we are more emphasizing on the arch form ok. So, depending on that how you create the arch as a door or entrance. So, that is being more predominant in this part.

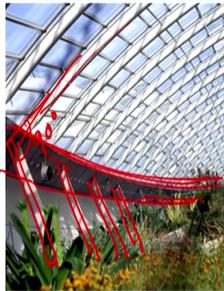
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Synthesis of Architectural and Structural Forms

Arches



Thrusts of the arches are resisted by a perimeter ring beam and columns that respond to the arches by their inclination normal to the ends of the arches



Great Glasshouse
Wales

Source: <https://botanicgardens.wales/garden-entries/great-glasshouse/>

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So, let us take another example this is in Wales. So, Great Glass house; so, here if you see that it is basically a multiple arch in both the direction creating this kind of you know structure and most interestingly to support this, so we they have a ring beam all along. So, if

you see this is been hidden by the glass, but here you can see that; here it is ring and then on top of that you have this thing.

And in order to support it in order to have the moods transfer of the load on top, they have some inclined you know vertical support a column which is basically the normal. So, they are making almost 90 degree to this support. So, it is transferring the load in that sense. So, this is another example of arches; so, mainly predominant its arch, but definitely this being supported with some other format. So, as we have discussed at the beginning that in building, there may be some multiple kind of structural systems; but looking at the dominance we will say or we will take that in some category.

Now, come to the folded plate, if you recall that in some of my lectures, I have explained with a plane piece of a paper and then, I folded and create some origami. So, it is something like that.

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Synthesis of Architectural and Structural Forms

Folded Plate



- The use of this structural and architectural form is mainly confined to **roofs, and sometimes walls**
- Inclined trusses may also form the folded plates

US Air Force Academy Chapel
USA

Source: https://commons.wikimedia.org/wiki/File:US_Air_Force_Academy_Chapel.JPG

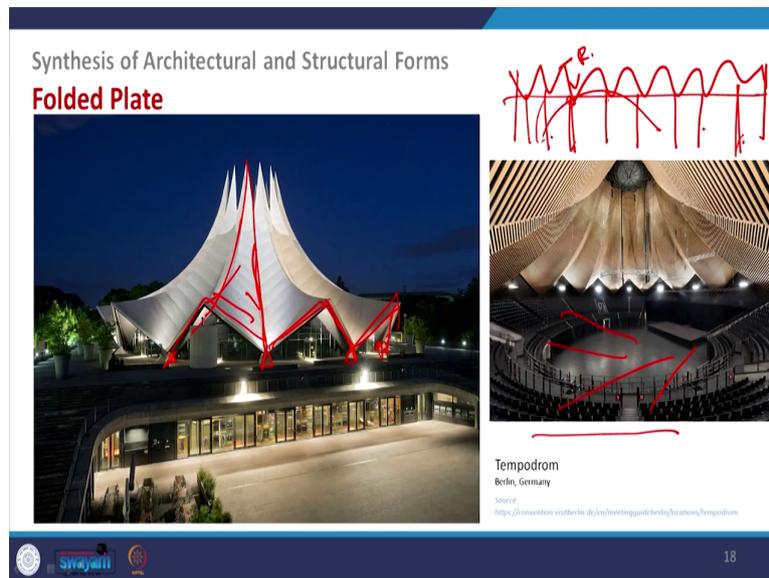
Source: Structure as Architecture by Andrew Charkson, 2015

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So, this is US Air Force Academy Chapel. So, here you see that it is being created with some folded plate giving the adequate strength and also the column free spaces. So, in order to make this convention hall, assembly hall some you know space for huge gathering which require the space to be column free so that we can use it. So, here this is the interior of this you can see easily that it is something like you know with the fold like the origami. We create different kind of you know form some animals, birds or some other form and this is the pretty similar.

The use of this structure is basically for the roof or sometimes in the wall and sometimes with some inclined truss, we can create the same. So, this is one example of the folded plate which is basically a structural form. But that also create the architecture of this kinds. So, it is making synthesis with architectural and structural form.

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This is another example of a Tempodrom, it is in Germany. This is basically a multipurpose you know auditorium different activity is going on different functions and again, in order to have clear view and other thing, it is it was mandatory to make this space column free and for that the options one of the options was to create it with the folded plate.

So, it is giving the strength. So, the region valley that will have different compression and tension, we will talking to that also in detail. So, this is something we can see that in state of a flame surface or you know domical surface that we have seen in many of the historical buildings. Here, it is something which been created with the folded plate that been supported, this valleys are supported at the end and it is taking the load. It is transfer, the transfer the load to the members and so, all our purpose to create the space as the way we want it to create.

And depending on the space depending on the requirement of the volume definitely design will change. So, this can be also used for the ware house, there we can have this kind of structure and we support some of the areas. So, wherever we have this you know valley.

So, reach is this top portion and valley is the down portion ok. For any mountain and this is pretty similar to that concrete can be used to it and some of the you know small gallery and all been made with wood. So, when we discuss about the structural materials, will again look back into this to create different kind of form what kind of material is suitable. So, we are coming towards end of this lecture.

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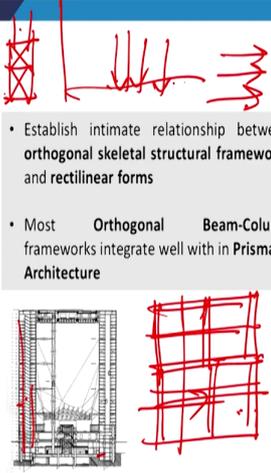
Synthesis of Architectural and Structural Forms

Framed Structure



La Grande Arche
Paris, France

Source: <http://www.architecturaldigest.com/photos/la-grande-arche>



- Establish intimate relationship between **orthogonal skeletal structural frameworks** and **rectilinear forms**
- Most **Orthogonal** **Beam-Column** frameworks integrate well with in **Prismatic Architecture**

Source: Structure as Architecture by Andrew Chalkson, 2015



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So, here we talk about the frame structure. So, again it is a combination of the beam and column. This is one example the La Grande Arche in Paris. This is also called frame with in frame. This is very good building we all appreciate it, but basically the fundamental thing is it

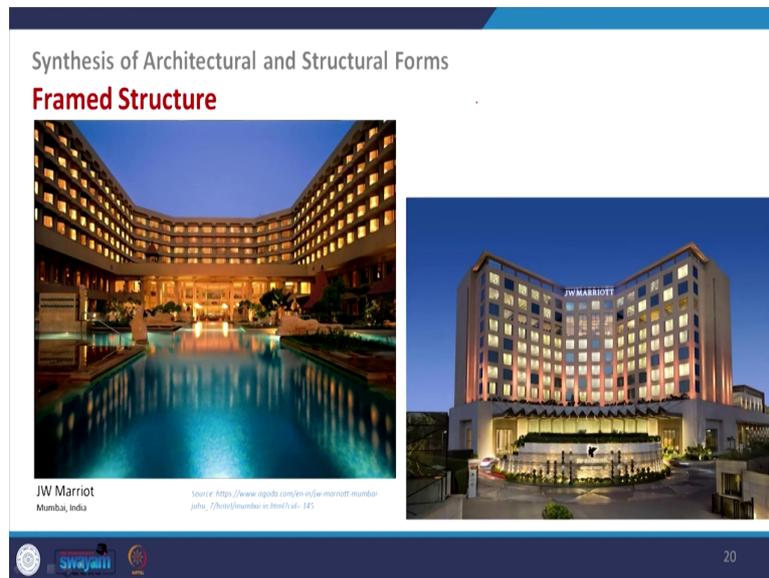
is been made with the some orthogonal skeletal structure being beam column combination and it is sometime also very you know very easy to make.

But nowadays we should not say like easy or very tough to create; everything is possible with proper execution, proper selection of the material, technique and available technology. But here this form is been created with a frame, where like you have a series of you know column and then, it being supported with the beam then top of that again it will go on. So, it is making a skeleton.

So, normal housing also we see those buildings are of this frame structure. But it has some limitation in terms of the height. So, when we discuss about the evolution of high rise building, there we will see that when height goes up. So, along with that gravity load; gravity load is the self weight acting towards the ground the center of the earth. And there is another called lateral load like wind and other thing.

So, the gravity load and other thing is can be taken well care of this, but when you go vertical as we have seen in the load that with the increase of height wind load wind pressure will also increase. So, there we have to support it with some other advance technique. So, we moved from framed structure to the tube structure, we can also add some structural bracing to extra support. So, anyway we will not discuss it now. Further like more detail, we will come to that how to get that thing to get the desired height of the structure.

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So, move to the next example. This is example from India, Mumbai this is a hotel building again is very simple. So, made with some column and you can see the visible thing is also showing visually the grid form. So, this is also a example of an example of frame structure.

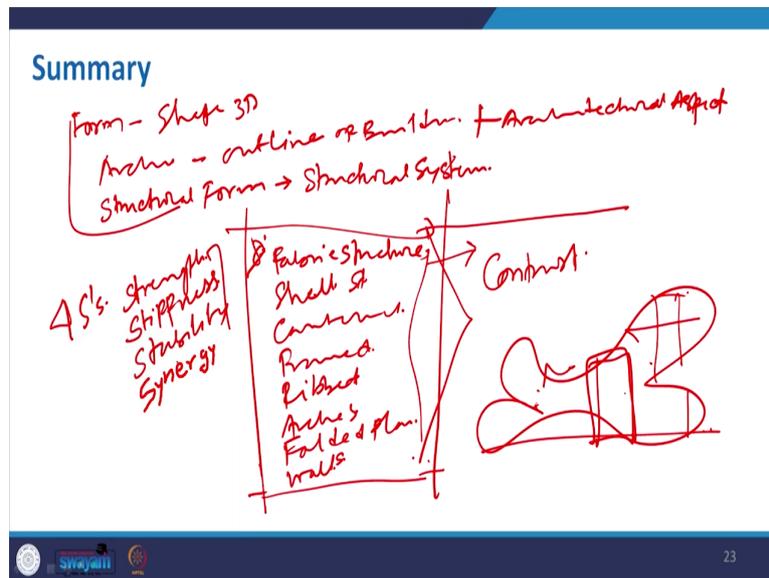
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So, move to the next example this is Saint-Ange residency in France. Here, if you see this is something like looking at the building, it is basically the wall ok. The wall all the side, but as I mention that you can also create some transparency by creating or providing some of you know some transparent element to it because this is the opaque.

So, opaque transparency you all know; like opaque is something you cannot see through transparent where you can see through. So, here we can see that this glass use of glass can give you a visual connection from for the people who are you know staying inside to the outside world, but here it is predominantly the structural form is the wall which is creating this architecture.

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So, in this we are now to summarize and here like let us just the way we have discussed. In this presentation, we know that what is the form? Your form is shape. So, 3D and then, further we discussed architectural form. So, not only this is basically outline of the building ok, but plus some other architectural aspect ok.

Now, next to that what we have also learned that structural form. So, here what we said that which is the predominant structural system of the building, we called that or considered that as structural form. So, from there we just come to a conclusion that it should be structural system rather than a structural form and then, after that we also discussed about 4S's which is very important. Number 1 is not in particular order.

So, one is your you know Strength, then you have your Stiffness, then you have Stability and then, the Synergy. These four components are essential to create it and next to that the

synergy the synthesis which when architectural form depending on the predominant structural system that is installed to the building.

So, based on that we have 8 categories; so, under 8 categories what are those. So, like if you can recall the first, we started with the structure just you know not in orders. So, let us start with the fabric structure. Then, you have shell structure that was the first one. Then, you have also discussed with the catenary ok. Then, framed; then, we have called ribbed which is skeleton type. Then, you have arches and then, you have folded plate and then last, but not the least we also called discuss with the walls.

So, with all these, we create a particular predominant structural form which is visible in our architectural buildings, we have seen many examples and there are more many more. So, I advise you all like I have only given you few examples. So, depending on that you also try to you know explore more examples and you know in some forum, we will also discuss it like how to define it which is the predominant of that building.

So, I love to see those you know questions and those you know discussion, looking forward to that. But you know all these things like sometimes it is predominant, but at the beginning of the lecture, we start that a building may consist of multiple structural systems right. So, they may create sometimes something different like not coming into the category. It will just create some contrast ok.

Out of that, we may have a building like this, where it is very tough to define or put it in the category. Somewhere it is in a combination on the frame or sometimes it may be the sales structure, some part of that folded structure. So, it create beauty. Overall we appreciate it, not a particular dominant structure, but overall composition creating a contrast creating something very beautiful.

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Further Reading

- Charleson, A. W., 2005, *Structure as Architecture*, 2005, Elsevier
- Ching, F. D.K., *Architecture: Form, Space & Order*, 2nd ed, New York: Van Nostrand Reinhold, 1996
- Salvadori, M and Heller, R. A., 1986, *Structure in Architecture*, 3rd ed., Prentice Hall
- Schodek, D. and Bechthold, M., 2013, *Structures*, 7th ed., Prentice Hall



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So, definitely we have really interested in looking at that and with that the upcoming 2 lectures basically the single topic that will you know discuss that is connecting structure and architecture. So, here we will see different kind of where sometimes structure is predominant or sometimes your architecture is predominant, sometimes it followed, sometimes it is some unorthodox or something you know not orthogonal. So, we will see that.

So, that is that will be our lecture number 6 and 7, connecting structure and architecture and these are the reference, so you can. I have added one more example that is a book written by D K Ching Architecture: Form, Space and Order. You can go through it and I have also given the references for all the (Refer Time: 60:12) sources, you can go and get more detail. And again, I would like to thank you all to take part in this course and till the next lecture, bye, bye.

Thank you.