Metal Additive Manufacturing
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Lecture 21
Design for Additive Manufacturing (DFAM) [Part 2 of 2]

Welcome to the next lecture in Design for Additive Manufacturing where we are focused towards design for additive manufacturing alone.

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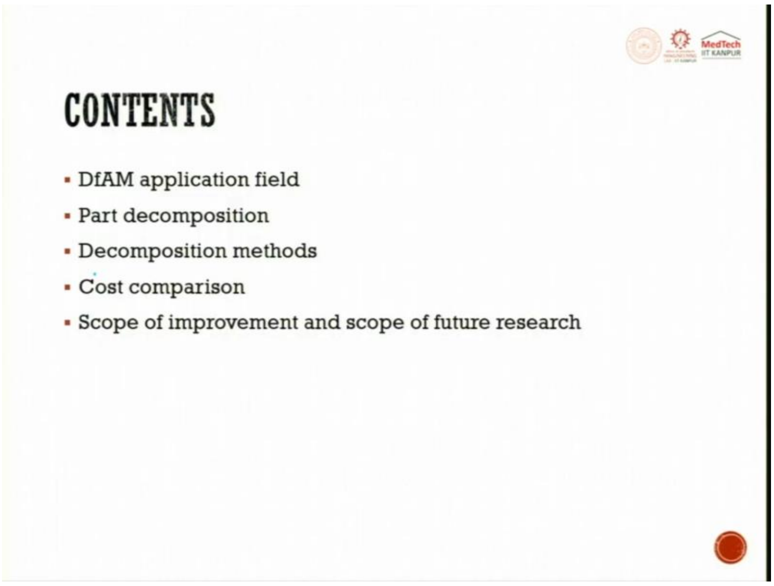

In this lecture, we will focus more on applications, then we will try to see how does part decomposition helps us in building a part, then what are the different types of decomposition methods, cost comparison and finally, scope of improvement and scope of future research.

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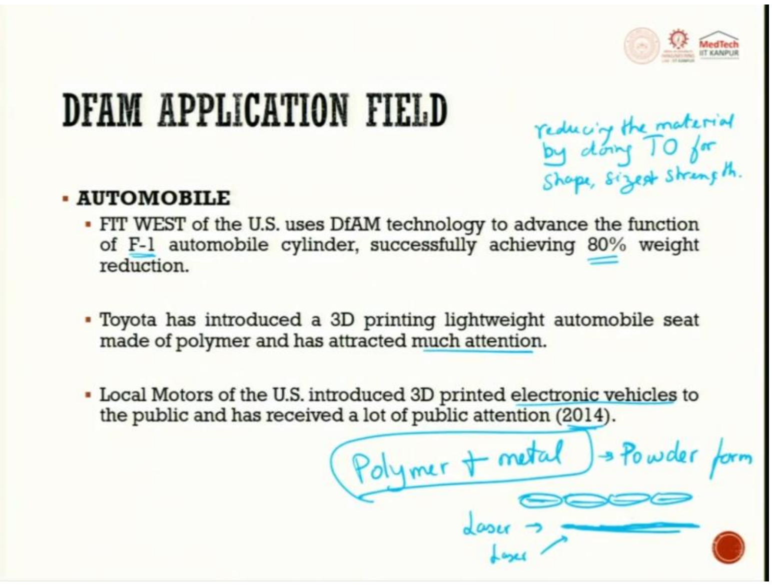

Metal additive manufacturing has not reached its matured stage. It is still in the infant stage. Lot of new, new parts and products are getting developed. As and when it is getting developed, it finds its way in various industries. So, the most prominent industries which use metal additive manufacturing are automobile, aerospace and space, naval and some exotic applications which is even used for entertainment industry.

The automobile is one of the biggest giants which use this 'design for additive manufacturing'. They use it because their business is very competitive and they would like to produce lightweight, cost effective, mileage effective products. FIT WEST of the US used design for additive manufacturing technology to advance the function of F1 automotive cylinders which successfully achieved 80 percent of weight reduction.

The weight reduction predominantly comes from reducing the material used by doing topology optimization for shape, size and strength. So, the weight reduction also led to the time in which the parts are produced. In metal additive manufacturing, part consolidation is the biggest achievement, so 80 percent weight reduction means they at least make 60 percent reduction in the processing time.

Toyota has introduced a 3D printing lightweight automobile seat made of polymer and has attracted much attention. So, it is trying to customize it to your requirement and then try to do it. See, the automotive companies, today, they are trying to make two-seater car, high performance where in which the seat is customized to the owner. Local motors of the United

States introduced 3D printed electronic vehicles to the public and hence received a lot of public's attention in 2014.

So, electronic means here what they do is they use polymer plus metal which is blended together in a powder form. This powder form, in turn, what happens is you try to assemble them and then you try to burn the polymer, you get all the metals. For example, let us assume, these are the polymers and these are the metal powder, which are ingredient.

So, now, when the laser passes on top of it, the polymer all removes and you get different metal powders which are getting aligned. Now, this again, we use a laser to burn this metal, metal powder, so, it forms a continuous link and this link is used for making electronic circuits and electrical vehicles are also made out of 3D printing.

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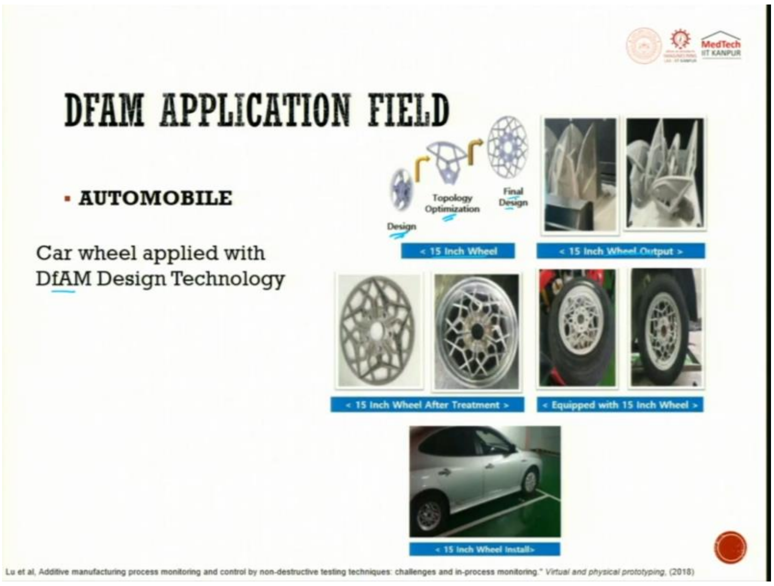

So, the initial design was this. After topology optimization, it was converted into this. The wheel cover or the rim or the spoke, the initial design was this fully made out of metal, then they did lot of topology optimization and finally they generated a beautiful pattern having lot of strength and ductility in the hub.

So, then this is the final design. So, this is 15-inch wheel. So, this 15-inch wheel, after treatment, while printing it is like this and after treatment, you get to see the performance like this, equipped with a 15-inch wheel which gets into automobile, today. You design your wheel rim to your requirements which is a part of mass customization. So, you can see that the wheel output, how is it looking like. So, the car wheel applied with DfAM design technology is coming up in a very big way.

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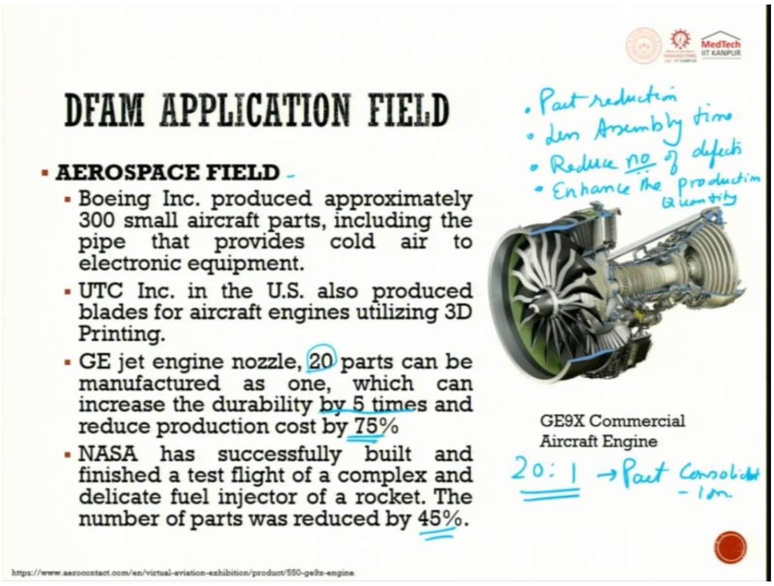

Aerospace industry is the other big industry, which uses metal additive manufacturing. They also start exhaustively following design for additive manufacturing. Boeing Inc. produced approximately 300 small aircraft parts including the pipes that provide cooling air to the electronic equipment through metal additive manufacturing.

UTC Inc. in the United States also produced blades for aircraft engine utilizing 3D printing, all are metal printers. GE jet engine nozzle built, 20 parts can be manufactured as one. They have made 20:1. So, look at the part consolidation. Part consolidation which is very high.

So, which can increase the durability by 5 times and the production cost is reduced by 75 percent. Huge reduction, a big transformation in thought process. NASA has successfully built and finished a test flight of a complex and dedicated fuel injector of a rocket. The number of parts were reduced by 45 percent.

So, all these things very clearly save. There is a part reduction and this part reduction leads to lesser assembly time, lesser assembly time and in leading these two, it also tries to reduce the number of defects. Then it enhances the production quantity. So, these are the big advantages for using metal additive manufacturing.

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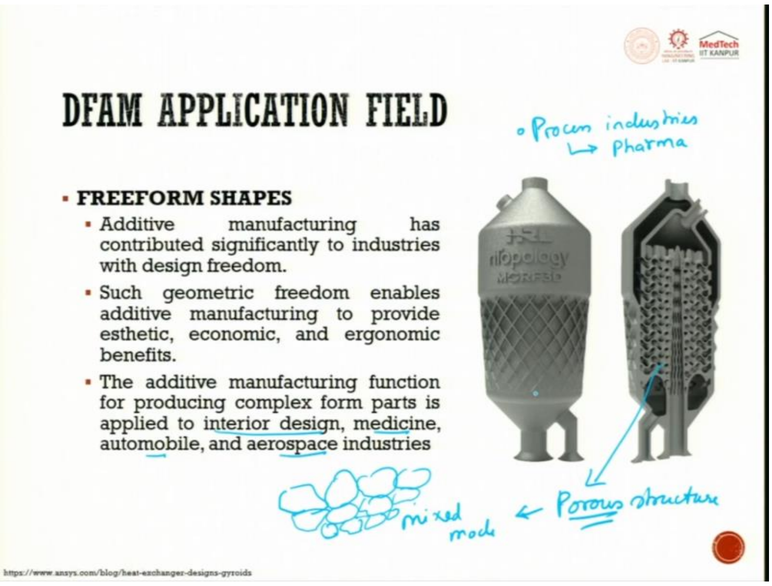

So, when we have free form surface, these free form surfaces also can be made. Additive manufacturing has contributed significantly to industries with design freedom, for example, process industries. In process industries, you can see that there will be lot of baffles which are there.

There will have lot of porous structure. These are all porous structures. All these porous structures are nowadays used for enhancing the surface area. Moment, there is an enhanced surface area, the heat rejection will be very fast and through this porous structure also they are able to trap multiple elements or particles which flows along with the fluid.

This, the porous structure can also be hierarchical. Hierarchical means it can be in a mixed mode. So, you can have a larger hole in the lower version and then this, the next one, it can be reduced in size. So, this is the next smaller holes which are there. And then subsequently, it can be reduced to a smaller hole.

So, these are hierarchical features and these hierarchical features can be used for heat and mass transfer exchange. Such geometric freedom enables additive manufacturing to provide aesthetic, economic and ergonomic benefits. The entire maybe a boiler or a filter is built through additive manufacturing.

The additive manufacturing function for producing complex form parts is applied to interior design, medicine, automobile and aerospace. Predominantly, process industry and in particular, pharma are today trying to explore or exploit the advantages of additive manufacturing.

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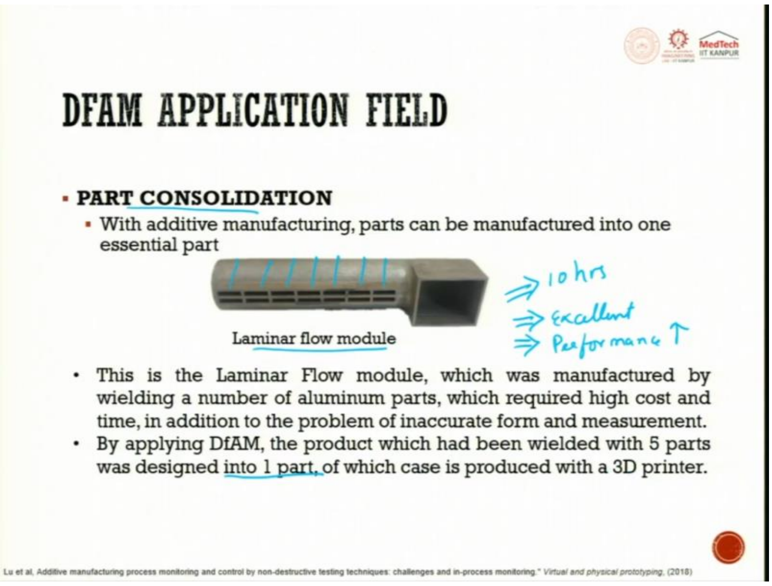

When we talk about additive manufacturing, the biggest advantage comes to it because of part consolidation. With additive manufacturing, parts can be manufactured into one essential part. If you want to make such independent small, small, small slots which is running along the direction then you will be finding it very difficult to machine. But whereas, if you decide the orientation properly, you can try to build these slots running along the direction so nicely.

So, if you wanted to have a laminar flow module, it can be easily developed through metal additive manufacturing. So, here, it talks about part consolidation. This is the laminar flow module which was manufactured by welding a number of aluminium parts which required high cost and time. In addition to the problem of inaccurate form and measurement, this part was taking a lot of time in building.

But today, the entire part is built within 5 to 10 hours, depending upon the accuracy you want. And the quality of build is excellent and it gives higher performance. By applying DfAM, the product which has been welded with five parts was designed into one part, of which, case is produced with a 3D printer. So, this is a biggest example for part consolidation.

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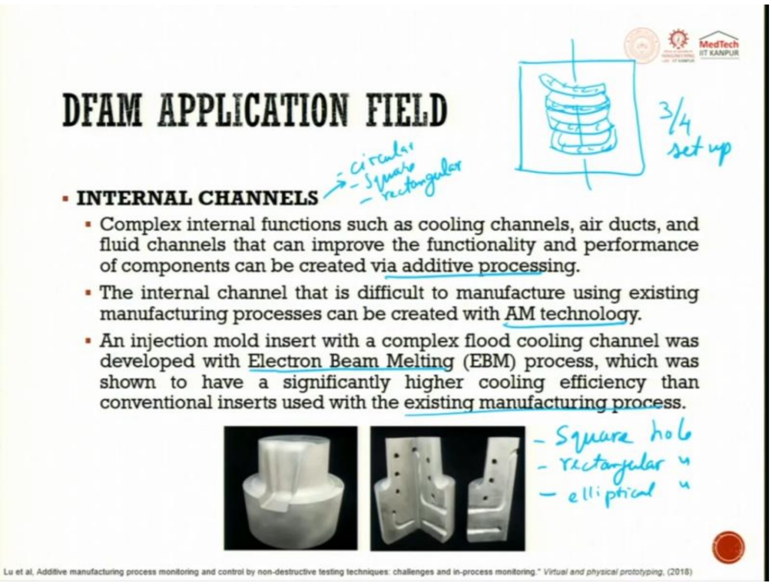

Internal channel forming. Suppose, you have a cylinder and inside the cylinder if you want to have grooves, you have to have grooves for application. So, these grooves, it is very hard for you to continuous grooves, if you, very hard for you to develop without splitting the component.

So, here, what happens is these internal grooves, whatever it is, these internal grooves are easily doable by this metal additive manufacturing. The internal channels of varying cross section area, it need not be circular, it can be square, it can be rectangular, it can be anything. So, now, these complex internal channels can be done to meet out to the requirements.

The complex internal functions such as cooling channel, air duct and fluid channel that can improve the functionality and performance of components can be created by an additive manufacturing. When you are trying to build it layer by layer by layer, you can easily get this done, very fast.

Otherwise, you have to produce this by making three or four setups and then finally you make it. And after you make it, you will have to weld it, which is again a major challenge. The internal channels that is difficult to manufacture using existing manufacturing processes, can be created by additive manufacturing technology. For example, a square hole, very difficult, a rectangular hole, an elliptical hole, all these things are very difficult to be made.

And injection mold insert with a complex flood cooling channel was developed with electron beam melting process which was shown to have a significant higher cooling efficiency than the conventional inserts using the existing manufacturing process. So, such things cannot be created so nicely, here, you will create such objects with internal cooling while building itself. So, this is a biggest advantage ever additive manufacturing can give.

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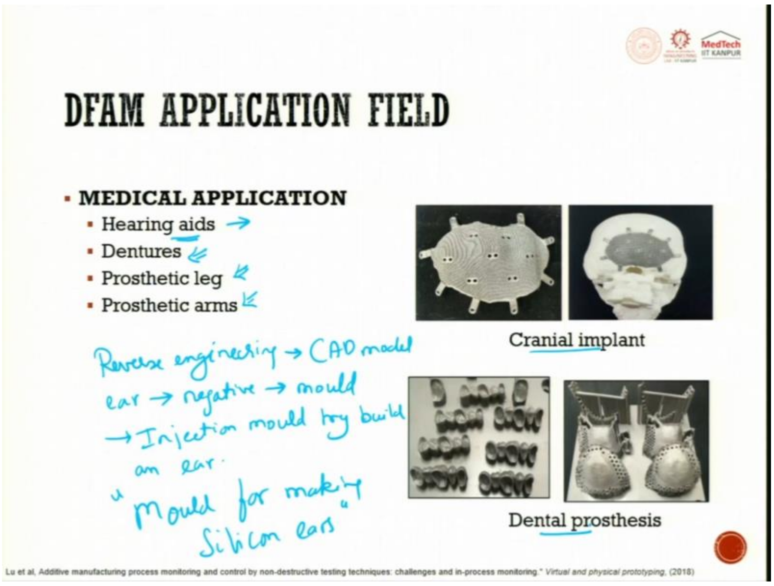

Few of the medical application devices which are now thought of in a big way is hearing aid. While doing hearing aid, it is very interesting. They use reverse engineering and after doing reverse engineering, they try to develop the CAD model for the ear. This is of course done for plastic and I am trying to explain it for metal, for where in which we make a mold.

So, CAD model for the ear is made. From here, they may take a negative and this negative is used to make the mold and from the mold you can inject, injection-molding process you can use and try to build an ear. So, I here use this hearing aid, whatever it is, I am trying to make a mold for making silicon ears. This is what we are trying to move.

Hearing aid. So, there are small, small thin flaps which are used or thin plates which are used inside the ear to maintain the balance. So, those thin plates are today manufactured using additive manufacturing, where the geometry is very complex. The dentures, which is used in dental applications, is exhaustively made out of metal additive manufacturing.

The cast is made out of polymer, but now the dentures, the fixtures whatever is placed so that is completely made out of metal additive manufacturing. Prosthetic legs are made out of metal additive manufacturing and prosthetics arm is also made out of metal additive manufacturing. Here, you can see here, cranial implants are made from metals which are placed in real time use. You also have dental prosthesis made out of it.

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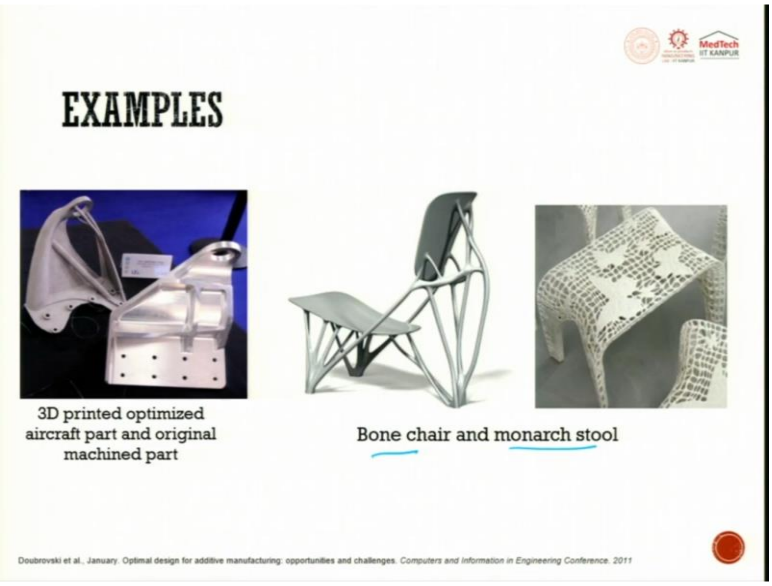

The other thing is 3D printed optimized aircraft part and original machined part, you can see here. This is the original machined part and this is the aircraft optimized 3D printed part for real time usage. See, the bone chair and monarch stool, these things are today made out of metals.

So, making this out of metals is very difficult for this design and the undulation which is given on the surface, if you want to bend and then set wire to it and then you do a welding process, it is extremely difficult. In order to get such free form surfaces with a particular design, it is very good to use metal additive manufacturing. This is called as a bone chair. Bone chair is just like a bone which supports the chair and where in which it gives you lot of comfort and stability.

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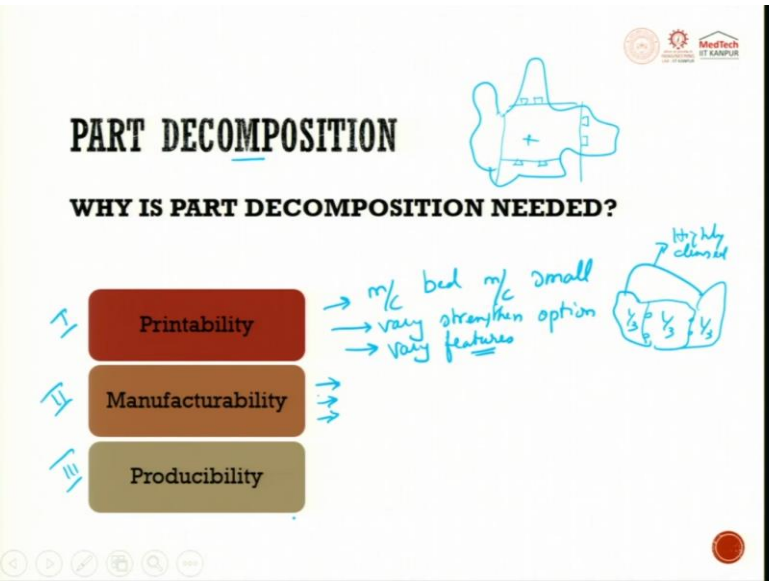

When we talk about part decomposition, when there is a product, the product has to be divided into small, small pieces so that each piece can be quickly built by using an additive manufacturing machine. So, part decomposition is very important concept, which is there, suppose, let us assume, I have an object something like this which is very large in shape.

So, now I should find out how do I decompose the part into small pieces and try to build them each, individually, and then at the joint, you have an algorithm which is already built in, which tries to give a provision for those dovetail joint and you get the final output. So, part decomposition is a very important concept as far as additive manufacturing is concerned.

So, why is part decomposition needed? Because it helps in printability. It tries to make the built, because you might have a limitation, machine bed size is small. So, when the machine bed size is small, you try to make it into multiple parts and then try to do it. Second thing is the part might have varying strengthening options.

For example, I draw this entire part. So, this part is divided into one-third, one-third and one-third and these two one-thirds you have to make highly densed. Densed means you have proper strength and proper load has to be taken and this one-third is only just to act as a bridge between these two.

So, here you do not spend lot of material. So, varying strength options if you want to have, so, you divide it into three options and then try to have. The next one is, if you want a varying intricacy or features to be made, you can try to break it and make it with small, small features and in three parts and then get it done.

I am not trying to talk in terms of welding or brazing but trying to split it and then have features and then try to consolidate into one-third or two-thirds. So, these are some things which gives you an option for good printable or sound quality output. Many a times the orientation of the object also puts a restriction on the printability. So, we always go for part decomposition.

Next is from the manufacturing point of view. If there is a limitation in the manufacturing that means to say, with respect to strength and with respect to microstructure and the bed size, whatever you have, so then that puts you into manufacturability difficulty. The producibility is here we are trying to talk about repeatability, reliability of the printed parts. So, all these three things are very very important, printable, manufacturable and the third thing is your producibility. All these things puts a restriction or puts a demand on part decomposition.

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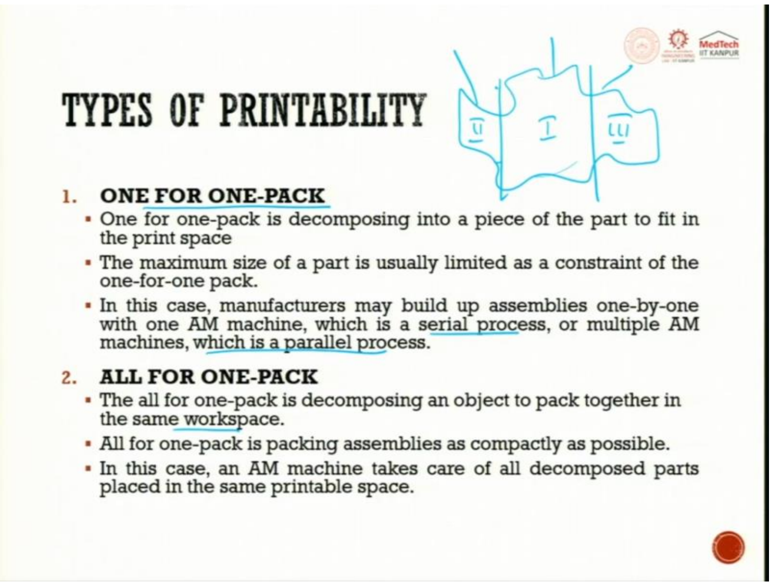

Types of printability when we are discussing, we the first thing is going to be one for one pack. One for one pack is decomposition into a piece of the part to fit in the printed space. Entire space is being printed by one piece. The maximum size of the part is usually limited, as the constraints of one for one pack is.

So, you have an area of 30 x 30 x 30 centimeter, you build the complete component in that given space. In this case, manufacturer may build up assemblies one by one with one AM machine which is a serial processor or multiple AM machines which are for parallel processing.

Today, what we are trying to say is you try to have a part. Now, this part is decomposed, depending upon one for one pack, so, which will go sit on a table and then you try to build. So, after you build this, the same machine is used to build this part and this part. So, this is one, two and then three. Finish this, then go to two, then finish this and then go to three.

All these things, if it is done in a single machine, it is a serial processing. If I split it and take it to three different machines, so, then I do parallel processing to meet out. So, one for one pack is always limited by the bed size. All for one pack is, for all one pack is decomposed and object to pack together in the same workspace.

For example, if you walk back in my lectures, I have shown an example where the complete cycle parts are getting printed or majority of the cycle parts are getting printed in one shot. So, that means to say, you have decomposed the complete part into small, small, small parts. All the parts are kept on top of a table and all of them are getting printed in one shot that is called as all for one pack.

All for one pack is packing assemblies as compactly as possible. In this case, an additive manufactured machine takes all decomposed parts placed in the same printable space. So, here also, you have to use lot of software to split the part and try to arrange the part on top of a table such that the size, whatever it is, is properly placed and each part gets the necessity or the demanded orientation while building, which in turn dictates the strength and the performance.

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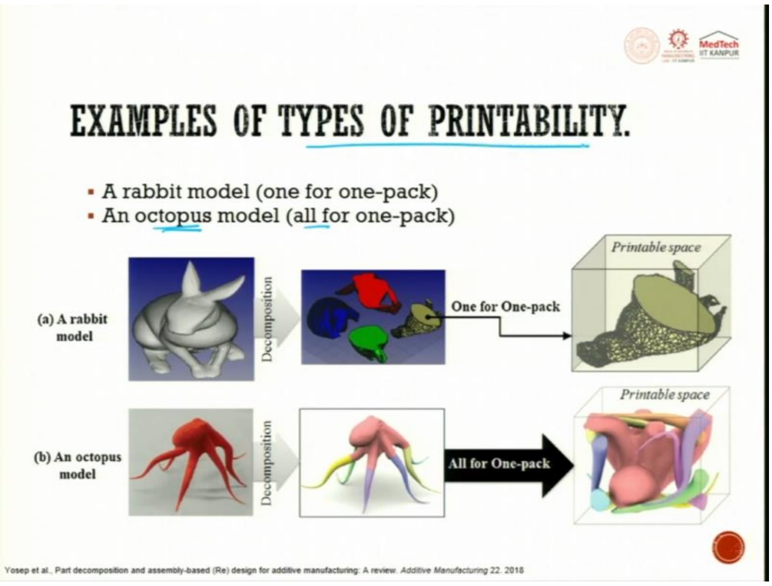

For example of types of printability, a rabbit mold, one for one piece. This is a rabbit mold which is done decomposition. You can see all these things and 'one for one pack' is a printable space looks like this. When we are looking for 'all for one' is an octopus. So, this is an octopus model. When we try to decompose, you try to see varying colors are there. These varying colors can give you varying strength properties. So, this is given by after decomposition 'all for one pack'. So, this is the examples for types of printability.

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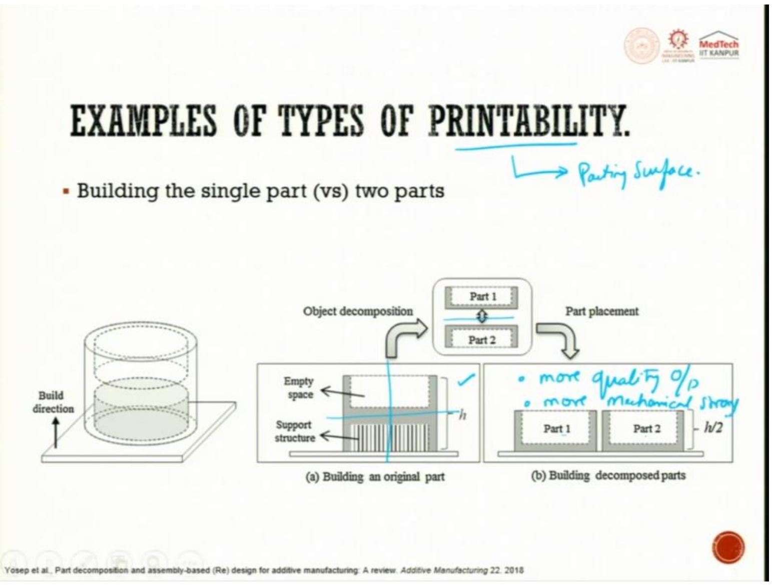

Example of types of printability building the single part versus two part. So, here this is the build direction and this is a complex part where there are internal, as I was discussing internal features, okay, so, here what we do is we try to have, this is the original part, here is an empty space, so here is a support structure and here is a part which is made and this is the height of the part. When we do object decomposition, you can try to do it like this or you can try to do it like this. So, parting line decision itself is a very important thing. So, you try to split it like this. Now, two parts are printed and these two parts will be assembled on each other to make this part.

So, when we try to do, talk about printability, we are also very much worried about the parting surface. Parting surface is where do I part such that I can make the symmetricity and use the existing space in developing the complete machine. So, now, you see that what was h here. Now, by h by 2, I make it into two parts, I assemble these two parts and I get the output. So, examples of types of printability is building a single part versus building two parts. This part is giving more quality output and it is more mechanically strong.

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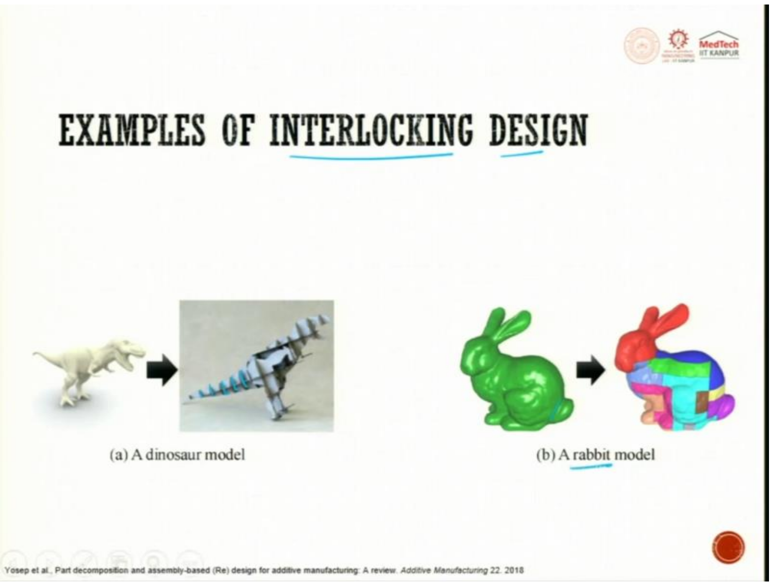

Examples of interlocking designs. So, interlocking designs are you see a dinosaur model. So, this dinosaur model is now built into several small interlocking and all these interlocking is used which can be built and you can see here this all can be assembled one with each other and then you try to build a part. Examples of interlocking design is now very much talked about. This looks to be very trivial. When we are using it for engineering applications, this is very very difficult to make.

So, you have 3D, you have all these interlocking which is coming up. Then you have a rabbit which is built in 3D and if you try to patch it up with so many different things, this is called as the interlocking design. Make several patches and these patches are assembled and then you try to make a complete rabbit.

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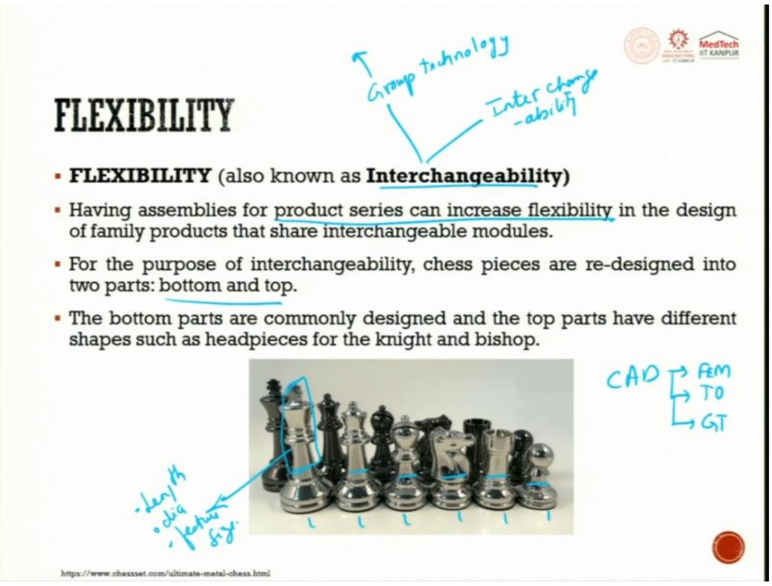

Flexibility. Today, we talk about interchangeability of the additive manufactured metal part. So, the flexibility, what we talk about is the interchangeability which is now getting introduced in additive manufactured part. Having assemblies for product series can increase flexibility in the design of family products that share interchangeability module.

For example, you try to build a shoe or fabricate a shoe. The die is almost constant. So, here what you do is you add and delete features such that you can try to increase or decrease the length of the sole. So, which is again injection molded. So, here what we do is try to build up such product series and try to increase flexibility in the design family so when you try to make a design itself, you try to put all these things together.

So, predominantly, what this we are talking about is follow group technology where in which all the parts of similar shape, size, feature will be put together and then you try to talk about interchangeability. Group technology, we will have to do the group technology concepts while at the design stage itself.

When we draw the CAD, we do FEM, we do topology optimization, then we try to do this GT. So, with this, all these things, we try to get to improve the part geometry such that we can try to produce the output. Having assemblies for product series, these are a series of products, can increase flexibility.

For the purpose of interchangeability, chess piece are redesigned into two parts, bottom and top. So, what they do is they try to have this portion, they just give a varying color or something like that, varying color they do and then they get it. The bottom part are commonly designed and the top part have different shapes such as headpiece for the knight and the bishop, separately. I try to make the bottom part, everything constant.

So, you look at it, all are constant. I split it and then I change only the height. So, this portion alone will be changed. So, when I change it, I try to increase the length, the dia and the feature size, okay, length, dia and the feature size, all these things are done, so that I try to get the best out of it. So, having assemblies for product series can increase flexibility. For the purpose of interchangeability chess piece are redesigned and the bottom part are commonly designed and the top part are changed. This gives you a flexibility in the production.

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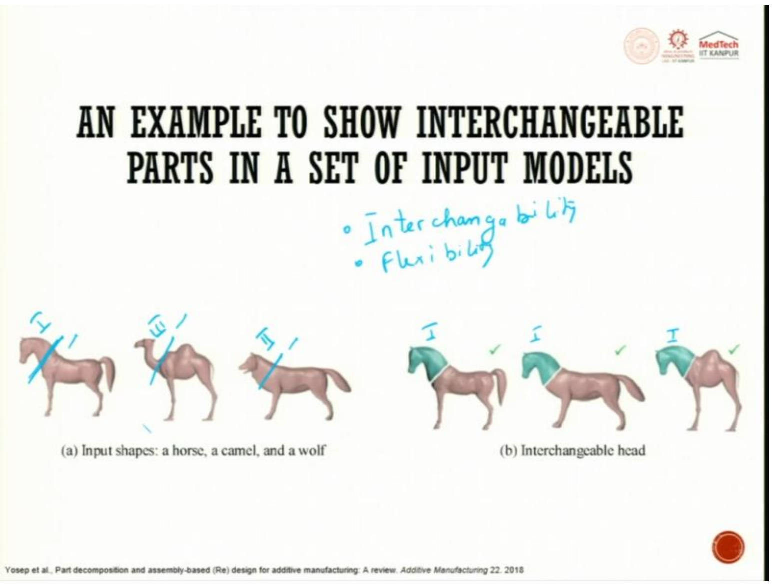

An example to show interchangeable parts in a set of input models. So, you have input shapes. This is a horse, a camel and a wolf. If you look at it, I try to section the head alone; of course, you will try to have changes. So, I try to section this fellow and this fellow, I can still use almost the same thing with some modification. Camel is an odd man out.

So, I can try to do camel also. So, if I, camel is three. So, if you see that I have made a portion which is common, okay. So, this is common, this horse head is one. I have placed the horse head on top of the wolf's head, which still looks to be okay. I place the horse on top of a camel which also looks to be okay.

But in the sense, the fixing I am talking about, but in reality it will never happen. I am just giving you an analogy so that tomorrow you can try to understand what is the importance of interchangeability and flexibility while designing the additive manufactured part. This is an example which shows interchangeable parts in a set of input models.

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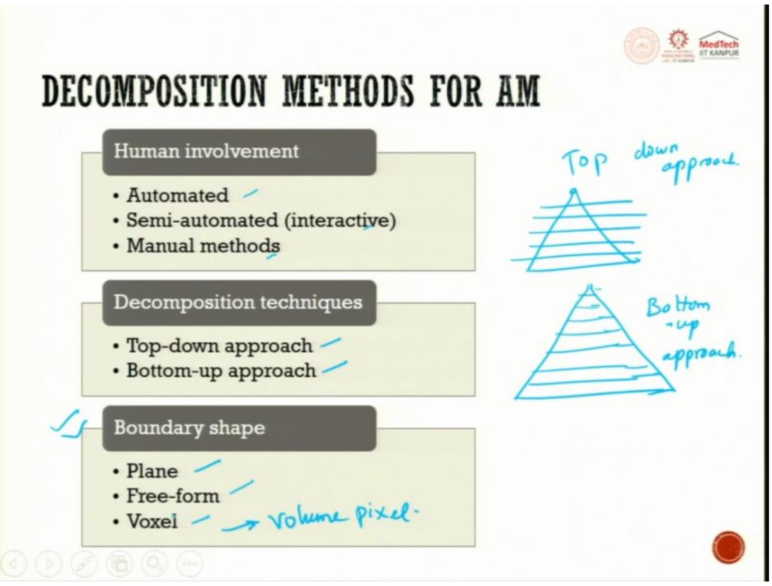

There are various ways of decomposing part. So, the decomposition methods for additive manufacturing are human involvement, decomposition technique and boundary shapes. When we talk about human involvement, it is, you can have automated, semi-automated and manual methods.

Somewhere in which the human plays a very important role in trying to do it. The next one is decomposition technique. There are two approaches, top down approach and bottom up approach. Top down means from the top you try to go down and then start splitting for your requirements.

So, this is top down approach. The other one is bottom up approach. Bottom up approach. Generally, in layer-to-layer manufacturing, we always prefer to have bottom up approach. So, bottom up approach gives you lot of freedom in trying to develop the object. Next one is depending upon the boundary shapes.

We can try to find out whether it is planar or whether it is free form or it is voxel. Voxel I have already told you, it is volume pixel. So, plane, free form and this. So, these are the different decomposition methods which are used today. You can do it by, see, now, the exhaustively used one is boundary shapes which are plane, free form and voxel are used here.

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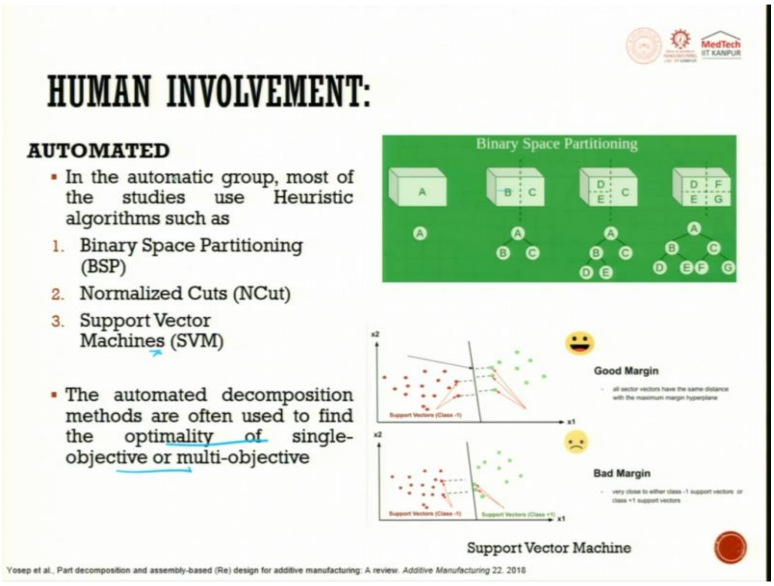

When we talk about human involvement, automated. In the automated group, most of the studies use heuristic algorithms such as binary space partitioning or normalized cut or the third one is support vector machines. When we do machine learning, we try to do support vector machine algorithm.

So, here binary shape partitioning is, you have a cube and this cube is divided into two parts. Then say for example, you have taken C, a B is now divided into D E and then now C is divided into F G. So, you are getting, so, it is completely A, binary space partitioning, then A is divided into B C then B is divided into D E and C is divided into F G.

So, it is all binary, in every step it has been done. The next one is normalized cuts which is almost the same like binary with some small modifications. Then the next one is support vector machine. So, support vector machines are this. So, you have support vector, you have a line which tries to say like a process window which I was talking to about, anything which falls here are accepted.

Now, what you have is support vector class 1 and then support vector class 2 is there. So, now, you try to join a partition line between these two and try to move the pieces here, whatever it is. So, you try to have a good margin, support vectors have their same distance with the maximum margin hyper plane. This is maximum margin, that is a good margin.

Which is a bad margin is it exactly tries to draw and all the support vectors sit on it. This support vector machine learning is one of a very very powerful tool. Today, we exhaustively used in human involvement of part decomposition. The automated decomposition methods are often used to find the optimality of single objective or multiple objective. So, they try to do for single and multiple objective human involvement in under the automated classification.

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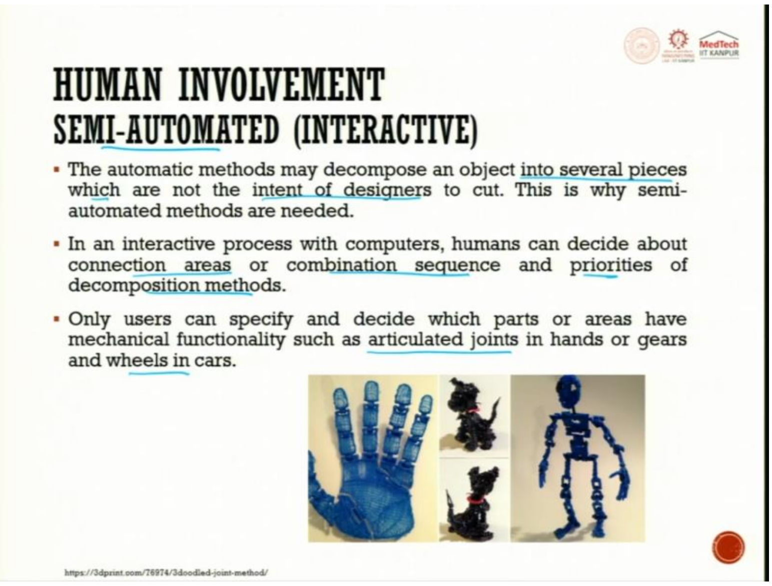

Next when we look at semi-automated or interactive type, the automatic method may decompose an object into several small pieces which are not the intent of designers to cut. This is why semi-automated methods are needed. So, you try to cut an object into several small pieces which are not the intent of the designer.

You might lose accuracy in the final output. But you have to do it because you are trying to build all in one space. This is why semi-automatic methods are needed. In an interactive process with computer, humans can decide about the connection areas or combination sequence or prioritize the decomposition method. So, the algorithm runs. It tries to give you the small bit pieces and then you try to find out, okay, I joined this two, this two, this two, this two and then you do it.

That is why it is called a semi-automated. Only users can specify and decide which part or area have mechanical functionality such as articulated joint enhanced or gears and wheels in cars. So, automatic first one is completely done by the system itself and all this automated, semi-automated falls under human involvement, which is one of the decomposition methods of additive manufacturing.

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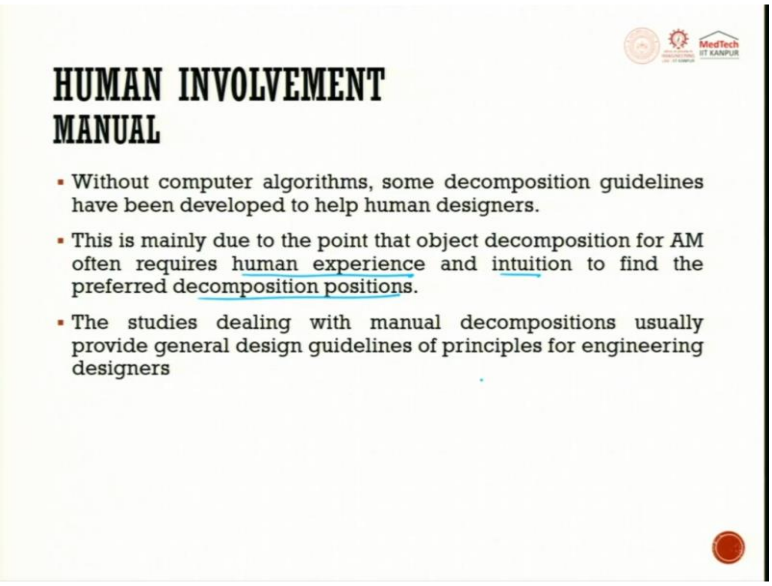

Next let us go to exclusively manual without computer algorithm. Some decomposition guidelines have been developed to help human designer. So, here no computer, human himself sits down and he tries to decompose. It might take time or sometimes he might miss some constrained equation which leads to the failure.

So, this is mainly due to the point that object decomposition for additive manufacturing often requires human experience and intuition to find the preferred decomposition position. The studies dealing with manual decomposition usually provides general design guidelines of principles for engineering design.

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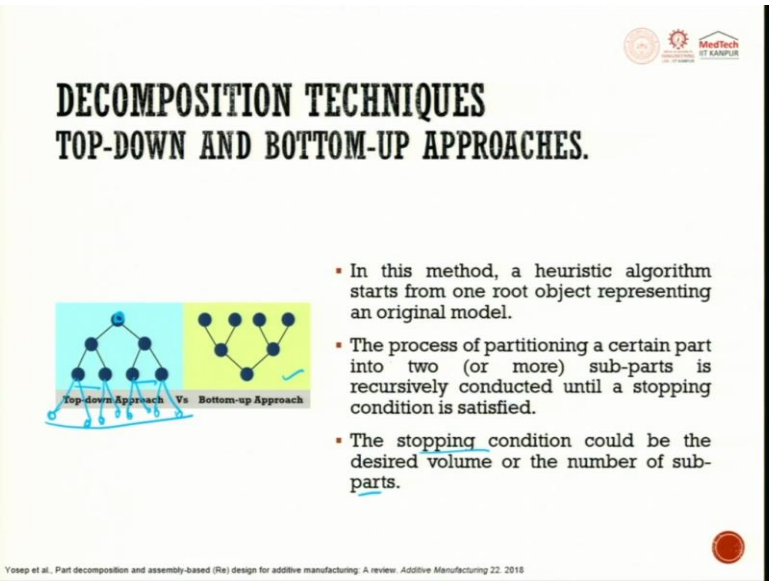

When we talk about decomposition techniques, which is top down and bottom up approach, this is the top down approach where in which you keep splitting into further divisions and bottom up approach is you have one and then you would start doing it. Both the methods are exhaustively used today but I would prefer to use more of bottom up approach such that your output whatever you get is more realistic and quality output.

In this method, a heuristic algorithm starts from one root object representing the original model. They start here. Then the process of partitioning a certain part into two sub parts is recursively conducted until a stopping condition is satisfied. It keeps on be splitting, splitting, splitting and then do it.

The stopping condition could be the desired volume or the number of sub parts that can be one. You can say that okay, you have an object, you do not split it more than 10 parts. So, that is the stopping condition. So, it will keep on be bifurcating and moment it has 10, here it is only 4.

Now, this will go to 2, this will go to 2, this will go to 2, this will go to 2. So, you have now 8, okay. So, now, this is 8, thus 8 will well again, so, now, I said 10. So, it will stop at 8. It will not go to 10. The same thing for here it will go like that. So, here the process of partitioning a certain part into two sub parts is recursively conducted until a stopping condition is satisfied.

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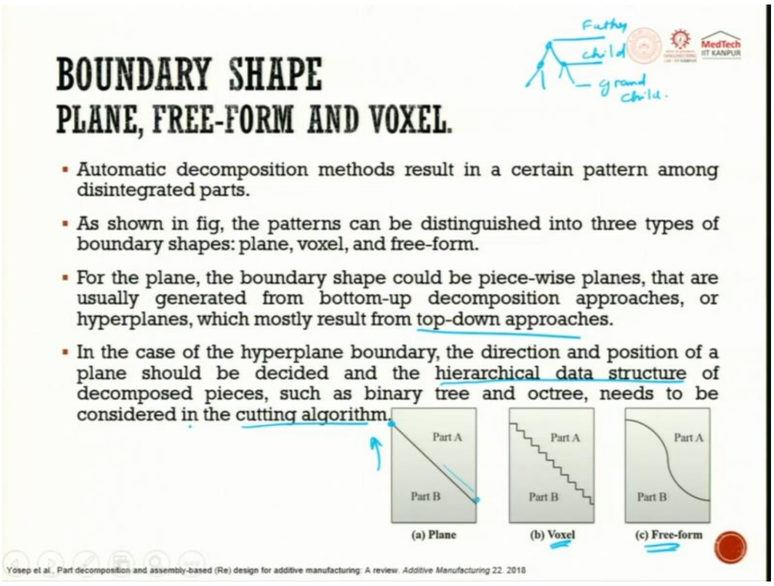

When we talk about boundary shape plane, free form and voxel, so, you see here between the object, you try to establish a single plane where in which it splits itself into part A and part B. Automatic decomposition method results in a certain pattern among disintegrated parts. As shown in the figure, the pattern can be distinguished into three types, boundary shape which is plane, which is voxel and which is free form.

This is voxel and this is free form. For a plane the boundary shape could be piecewise plane that are usually generated from bottom up decomposition approach or a hyper plane. A hyper plane is drawn which mostly results from the top down approach. This lecture what I am covering is a heavy lecture and it has lot of mathematics.

At this level of this course, I just wanted to give you an exposure, how are part decomposition happening. All these days, we were just thinking okay, if there is a bend, wherever there is a bend you try to split it into two parts, we weld it. But it is not so. In additive manufacturing, you try to use these decomposition techniques which can help you in producing good quality output.

In the case of hyper plane boundary, the direction and the position of a plane should be decided and the hierarchical data structure of the decomposition, decomposed piece such as the binary tree or octree needs to be considered in the cutting algorithm. How did I cut this boundary that is very important.

The direction and the positioning of the plane, the direction and the positioning of the plane should be decided at the hierarchical data structure. What is hydra hierarchical data structure? Top, whatever it is now. So, this is father, this is whatever, child and this is grandchild. The hierarchical data structure of the decomposed piece such that the binary tree and octree needs to be considered in the cutting algorithm.

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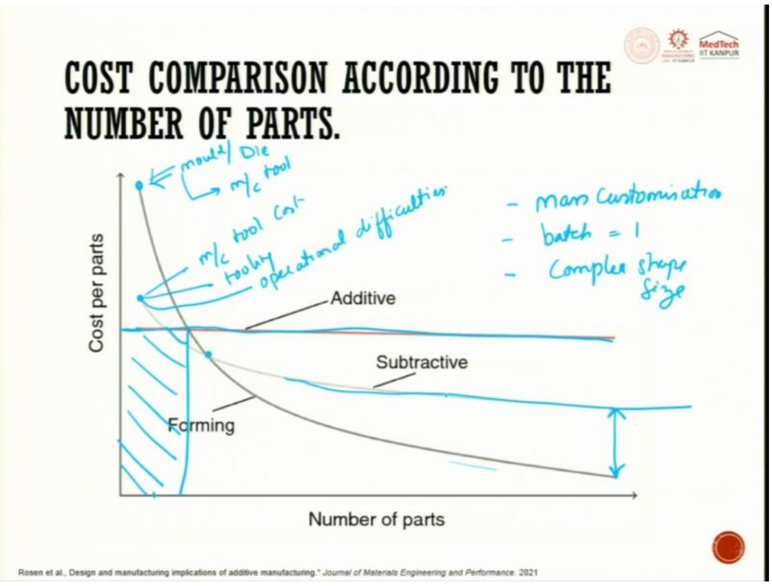

When we do a cost comparison, according to the number of parts for additive manufacturing, this is a very important thing. When we talk about cost per part, you can see here the forming falls like this. That means to say the cost if you try to produce number of pieces less, it is going to be exorbitant. Why?

Because here, you will try to make mold or you will try to make die and then the machine cost is expensive, machine tool cost is expensive, okay. So, now, if you want to produce only three-four parts it is going to be pretty expensive. Now, if you keep producing 100 parts or 1000 parts, you see there is a major reduction or exponential reduction in the costing.

When we start doing with the subtractive process, machine cost is very low, machine tool cost and the tooling cost is very low and the other operational difficulties are also very less, operational difficulties or also very less. So, you can see here. Here is the slope change and you can see it is costlier than the metal forming process but it after at a point of time it reaches some saturation.

So, the cost difference between subtractive and metal formed parts will be so much as and when you start increasing the number of parts. That is why you see when we start doing injection molding or when we do metal forming experiments, we always look for the batch size. So, this is very important.

On a contradictory, when you try to talk or when you try to compare with additive manufacturing, it almost follows a straight line which gets saturated as and when you produce one part or hundred parts the cost is almost the same. So, what is the inference of the story is? Wherever you want to do mass customization, mass customization and where the batch size is one, we prefer going to additive manufacturing.

So, you try to have various complex shapes. So, complex shapes also can be complex shapes, complex size could be made. We studied that decomposition technique you can try to make multiple parts and then assemble it to get the final part. So, additive manufacturing gives you a big benefit in this zone, in this zone.

So, this is a zone where additive manufacturing gives a huge advantage. So, this portion if you are able to produce cost per part, if you are able to do it, additive manufacturing is the only place where you can do. These two subtractive and forming tries to intersect at this point and you see after this point, the cost is going down and it gets saturated for both.

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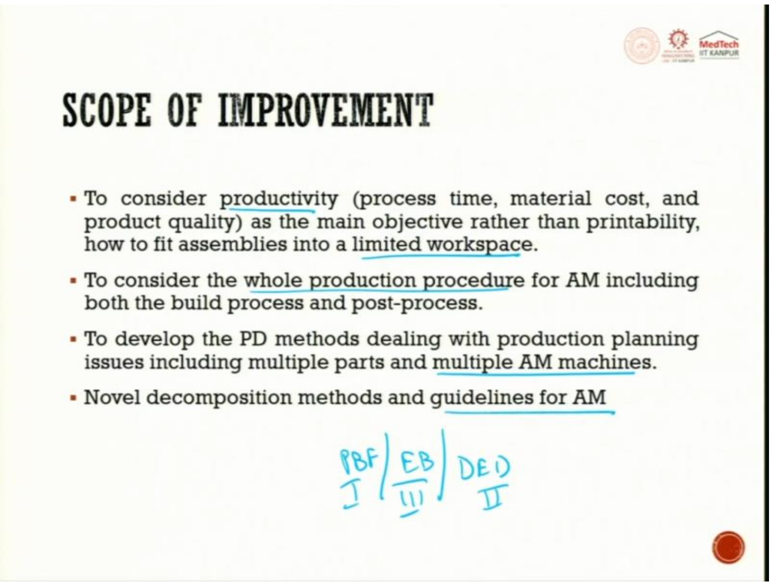

There is lot of scope of improvement in this additive manufactured part. When we start looking from the point of view of productivity, the processing time, material cost and product quality, even today, is a big challenge. Processing time, some of the parts which are to be printed, where the layers are even a small thin doll or a part you want to make and if you want to have the highest accuracy, we will try to do very thin layers.

So, the number of layers will be very high. The processing time for many of the rapid prototyping parts, normally, in polymers itself it runs for 78 hours, 100 hours, 150 hours. When we are talking about metal you can almost have the same thing. Processing time can be 5 days, 6 days, that is 24 into 5 100 hours, 125 hours such parts are being made.

The material cost as of today is exorbitant because it does not give you lot of freedom in the alloys and trying to produce high purity material are also expensive. Product quality, depending upon the process parameters the quality is dictated. As the main objectives rather than printable, how to fit assemblies into a limited workspace.

This is a big challenge and like your nesting layout which they follow for water jet cutting or for leather the same nesting methods are used for additive manufacturing today, and that too in the powder bed fusion method it is exhaustively used. To consider the whole production procedure of additive manufacturing including from the build process to post process, there is lot of scope for improvement.

When we try to develop PD, product development methods, dealing with the production planning includes issues, production-planning issues including multiple parts and multiple additive manufacturing. Again, there is a huge challenge, when we have multiple additive manufacturing machines.

So, one is PBF, the other one is electron beam and the other one is DED. If you make three parts, one part here, one part here and one part here and now trying to assemble it and trying to put into real time use, there is a huge challenge and there is lot of scope for improvement. Novel decomposition methods and guidelines for AM are still open for researchers to get developed.

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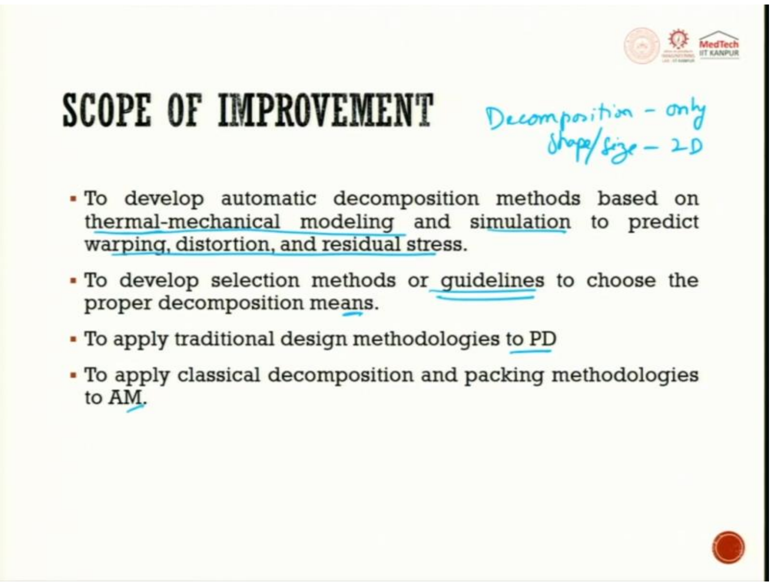

To develop an automatic decomposition methods based on thermal mechanical modeling and simulation to predict the warping, distortion and residual stresses are very very important. So, here to develop automatic decomposition methods based on thermal till now what we were doing is the decomposition, whatever we were trying to talk about, was based on only shape and size.

It was predominantly doing 2D. Now, we are trying to do 3D. And here we were only talking about the CAD model. Now, here we were trying to integrate the process parameter along with the CAD model. And then simulation, to predict the warping, distortion and residual stresses. To develop selection methods or guidelines to choose the proper decomposition means.

So, guidelines have to be also developed. One is decomposition and in that there has to be guidelines also given to apply traditional design methodologies to product design to apply classical decomposition and packaging methodologies for AM. So, these are places where there is lot of scope for improvement.

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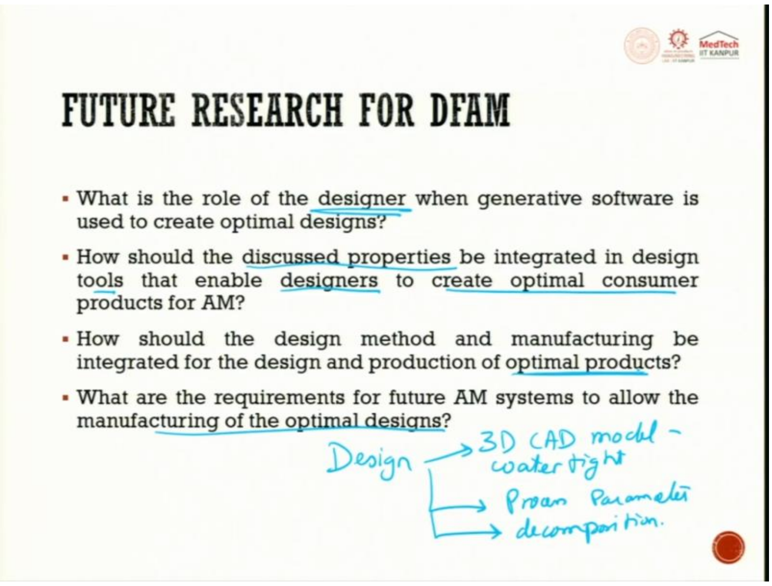

The future research for DFAM is what is the role of designer when generative software is used to create optimal design. Here, there is a huge research component getting into exist. What is the role of a designer when generative software is used to create optimal designs? When the software itself tries to create and when DFAM has to be integrated, how do we do it.

How should the discussed properties be integrated in design tool that enables designer to create optimal consumer products for additive manufacturing. How should the design method and manufacturing be integrated for the design and production of optimal products? This is a major challenge, the design methods.

So, we currently use minimum number of parts reduction, then you should try to have assembly when you are trying to do minimum number of part reduction, how should be the welding zone, how should be the parting zone, then how should be the extra material given, what should be the edge’s chamfer, all these things are, how should the design method and the manufacturing be integrated together to design and produce parts in a very optimal way, what are the requirements for future AM systems to allow the manufacturing of the optimum design.

These are all the scope for the future, future research are going on, where in which the existing design that means to say 3D CAD models, which are water tight. How are we going to use this and integrate process parameters and do decomposition to produce an optimal product is a major challenge.

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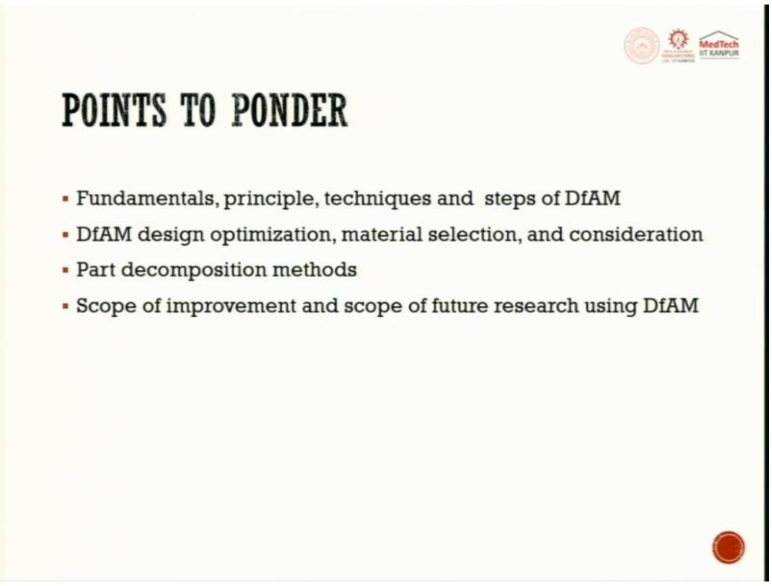

Points to ponder. What did we cover in these two lectures is we understood the fundamentals, principles, techniques and the steps of DFAM. DFAM design optimization, material selection and consideration were discussed. The part decomposition methods which is very important was discussed to bring in interchangeability and flexibility in the part development. The scope for improvement and the scope for future research using DFMA was also dealt.

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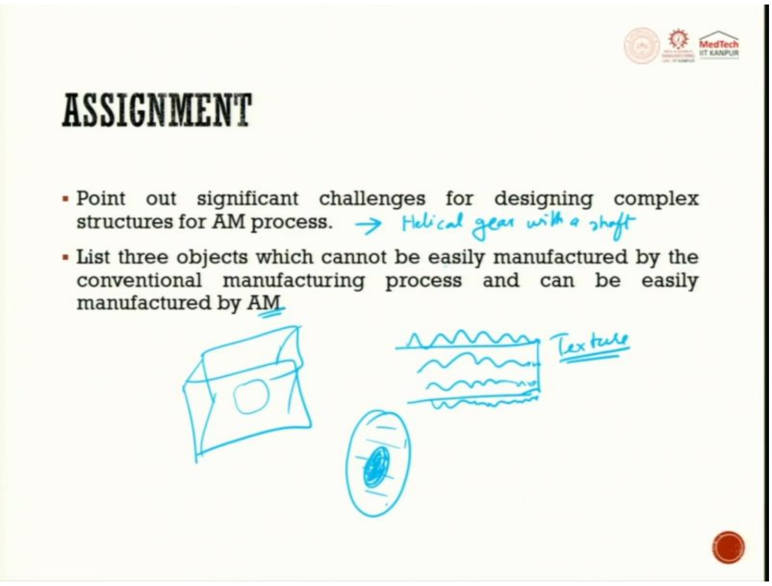

Now, looking at assignment like as usual, you do not have to submit these two assignments have to be solved by you for your understanding. Point out significant challenges for designing complex structure for additive manufacturing process. Here, I am going to give you a herringbone, we will do helical gear, helical gear with a shaft.

Try to take this part and try to understand all the challenges for designing complex structures with this. And second thing is you will have a helical gear. The next thing is you will try to have a surface where in which in this on the top of a surface you are trying to make textures and these textures are used for heat transfer or better contact, whatever it is.

These textures you try to make it on a surface, on a shaft and then try to see what are all the challenges you face for designing complex structures for AM process, okay. Next is list three objects which cannot be easily manufactured by conventional manufacturing process and can be done only by additive manufacturing. You think, you think of a component and let us know.

For example, if you have a square and inside in a square if you want to have a ball which is there inside which does not slip out but keeps freely rotating inside. If you want to develop such a part, additive manufacturing is very good. If you want to generate an egg, inside an egg, there is a yolk, this yolk can freely move, that freely move but it does not fall down.

So, that is a very difficult part to be made by conventional, you can easily make through additive manufacturing. Like this, you think of objects which can be made exclusively by additive manufacturing and not by conventional methods. With this I would like to come to the end of this lecture. I would like to thank you all for your patient listening. Thank you.