Metal Additive Manufacturing

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Lecture 20

Design for Additive Manufacturing (DfAM) (Part 1 of 2)

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Welcome to the next lecture in the series of Metal Additive Manufacturing, which is focused towards DfAM Design for Additive Manufacturing. Design for manufacturing is a very common concepts practiced, where there is a manufacturing shop and then there is an assembly shop. But there is a paradigm shift when we start thinking about additive manufacturing, where assembly is not a separate operation, it gets integrated in the fabrication itself. So, now, there is a major shift in design for additive manufacturing principles.

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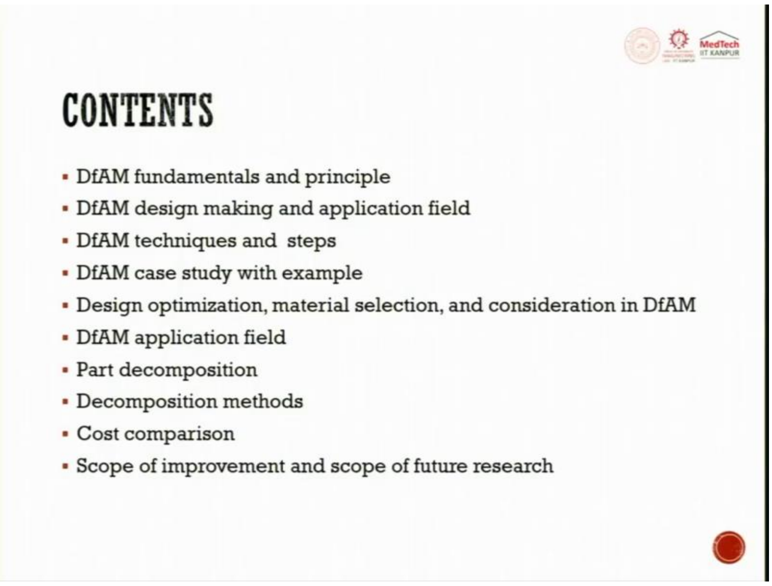

In this lecture, we will try to see DfAM fundamentals and principles followed by it, we will try to see design for additive manufacturing design making and application fields. Then, design for additive manufacturing techniques and steps. Design for additive manufacturing case study with examples. Then, design optimization, material selection and consideration in DfAM. DfAM applied field part decomposition, decomposition methods, cost comparison and scope for improvement and future research.

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Before we start DfAM, let us ask some of the questions to our self. How can we consider the relationship between the structure and performance? Which was never thought of in the past, only in DfAM, we have this thought process. What is the relationship between the microstructure and the performance? Microstructure dictates the performance. What are the trends in additive manufacturing fabrication techniques?

And how can they impact product design and realization? Trends in additive though additive manufacturing we say that everything can be done, but if we start looking at micro features. You want, anything less than 50 microns or anything less than 100 microns, then it is very difficult, there is a trend change in additive manufacturing techniques for such fine feature making.

And what is their impact, the change in additive manufacturing impact on product design and realization? How much it has reduced the time? And how quickly I can release the product to the market? So, this is another question which generally people ask before using DfAM. Then, what methods can be proposed to optimize performance? This is also a part of DfAM? What are the opportunities and limitations for the creation of optimal design. So, these are the four questions which are in front of us, which has to be answered by DfAM.

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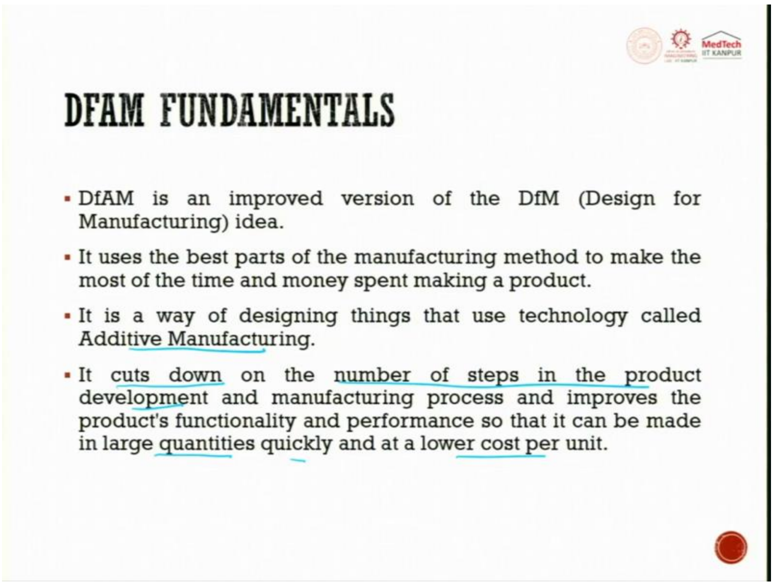

DfAM is an improved version of DfM, it uses the best practice of the manufacturing methods to make the most of the time and money spent making a product rather than losing it for waiting and then having spending more time in assembly, all these things will be slowly slowly tried to be removed and DfAM gives this explanation. So, it uses the best part of the manufacturing methods to make the most of the time and money spent making a product.

It is a way of designing things that can use technology called as additive manufacturing. It cuts down number of steps in the product development. So, we tried to initially think of casting, then we used to think of mold, then we used to think of injection, machine and other things. But now what is happening since the final part is made in one shot, the number of steps in the product development and manufacturing process are reduced drastically and it improves the products functionality and performance so that it can be made in large quantities quickly at very low cost or lower cost per unit.

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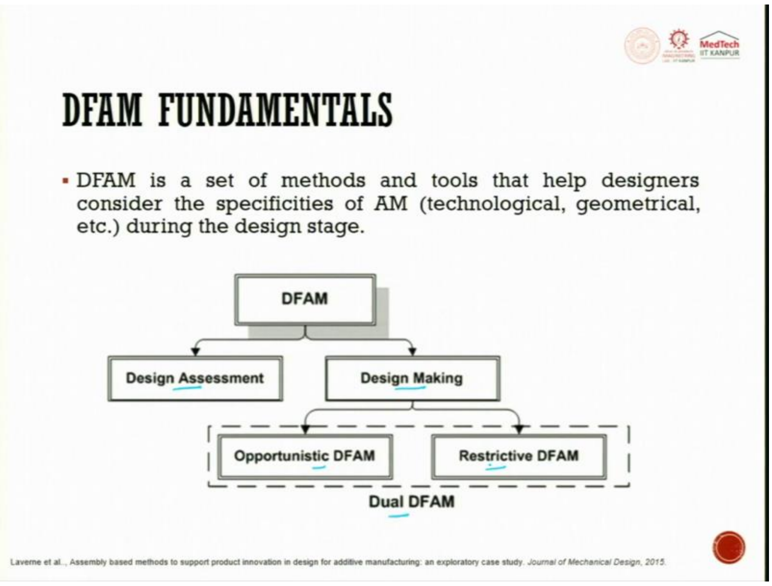

DfAM is a set of methods and tools that help designers consider the specifications of AM which can be technological, geometrical, etcetera during the design stage. So, DfAM is this. DfAM, it is divided into design assessment and design making, design making in turn is divided into opportunistic DfAM and restrictive DfAM. This two put together is called as dual DfAM.

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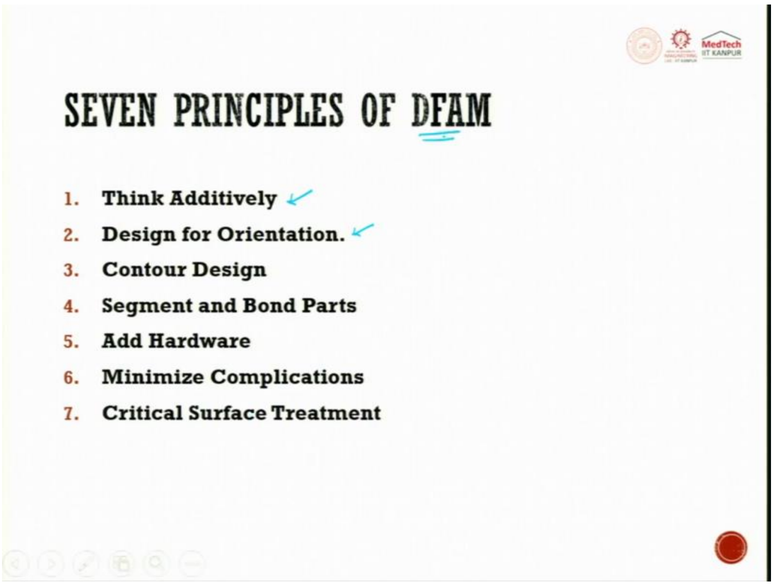

Seven principles of DfAM always think additively. When you have a component to be made, and if this component could be thought of using additive manufacturing route, then try that. Whenever you are looking at a part or a component or a full prototype, think whether it can be done by additive manufacturing. Next, design for orientation, how are we going to fix the part such that we try to get the maximum strength and minimum time for build.

So, that is what is designed for orientation. Contour design is also very important. The next one is segment and bond parts, you have to find out where you can exactly segment it and where you can bind it to get the final part done. The next principle is going to be add hardware as much as possible. Next one is, minimize complications. And the last one is going to be critical surface treatments. So, all these seven principles are very important for consideration of DfAM.

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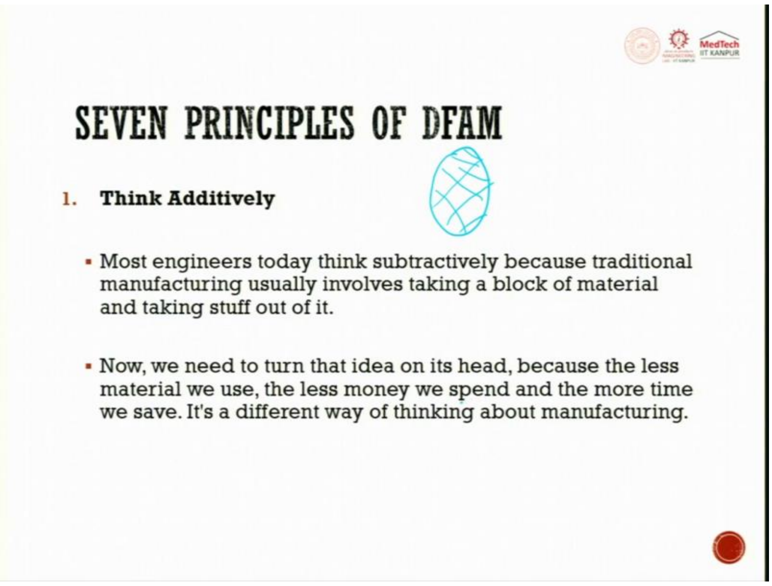

Think additively. Most engineers today think subtractively because traditional manufacturing usually involves taking a block of material and taking stuff out of it. Suppose, if I have an egg like feature, in the egg like feature, if I want to remove material and make something like a basket, if you want to do it by subtractive process, it is next to impossible. In subtractive process, what we do is we always start with a bulk material and we think of a process of removing it and trying to achieve it, but additive manufacturing is trying to build the part added at the required space material to get the final part.

So, think additively is your paradigm shift for design engineers. Now, we need to turn the idea on its head, because the less the material we use, the less the money we spend and more that time we save this is all talking about sustainability, sustainability in manufacturing, we are talking about it, because of the less materials we use, less money we spend, less energy we spent in developing the part.

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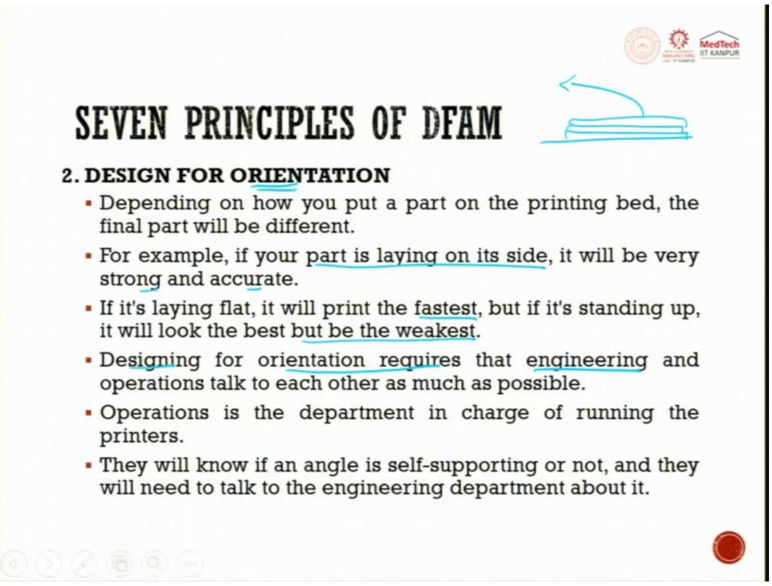

Design for orientation. Depending on how you put a part on the print bed, the final part will be different in terms of microstructure. So, when we try to design we do not design depending upon the microstructure, what we get with that can be useful for the product. So, depending on how you put a part on the printing head, the final part will be different. For example, if your part is laying on its side, it may be very strong and accurate.

If the part is laying on its side, then you will have a very high good strength and accuracy. If it is laying flat, it will print the fastest. But if it is standing up, it will look the best but it will be the weakest in terms of strength. So, what I am trying to say is if we tried to build like this, you can build a very long flat plate or a block first, but when we try to rotate him and bring him at 90 degrees this will be the weakest and it will fail first.

Designing for orientation requires that engineering and operations talk to each other as much as possible, for designing and engineering talk about the orientation required. Operations is the department in charge of running the printer. They will know if an angle is self-supporting or not. And they will need to talk to the engineering department about it to get it. So, design for orientation is very important when we are looking at properties.

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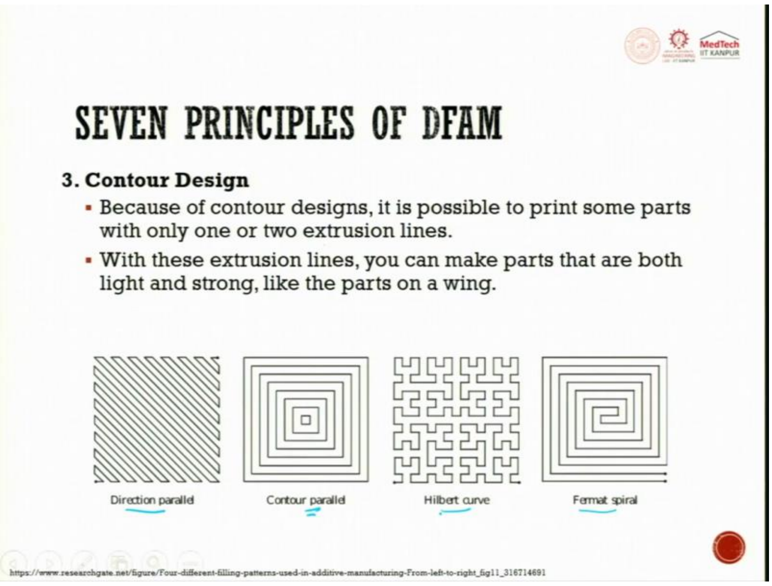

Contour design. Because of contour designs, it is possible to print some parts with only one or two extrusion lines. With these extrusion lines, you can make parts that are both light and strong like the parts on the wing. So, you can try to make contour, these are all kind of direction parallel. So, you can try to take a direction parallel is there, then this is contour parallel, then this is Hilbert curve, this is Fermat spiral, you can see here Fermat this is spiral, Fermat spiral. This is contour parallel. This is direction parallel. And this is Hilbert curve.

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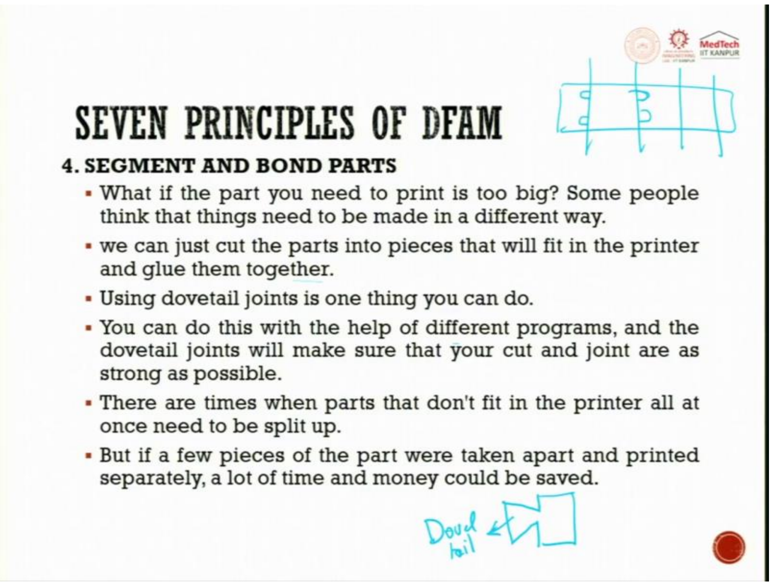

Segment and bond parts. What if the parts you need to print is too big? So, people think that things need to be made in different way. We can just cut the part into pieces. So, when you have a large part you cut into small small segments. At the point of contact you make the projection and then you make the recession. So, this will try to place the part inside it. We can just cut the part into pieces that will fit in the printer and glue them together.

Using double tail joint is one thing you can do. So, double tail is this, double tail joint. Using double tail joint is one thing you can do. You can do this with the help of different programs and double tail joints will make sure that you cut and joint are as strong as possible. So, nowadays when we are talking about intelligent machines, when you have a large part, it will try to section at some parts.

And it will try to also suggest us what is the joint you have to use such that the final application can be met. There are times when parts that do not fit in the printer all at once need to be split. But if a few pieces of the part were taken apart, and printed separately, a lot of time and money can be saved. So, they are trying to talk about make it modular.

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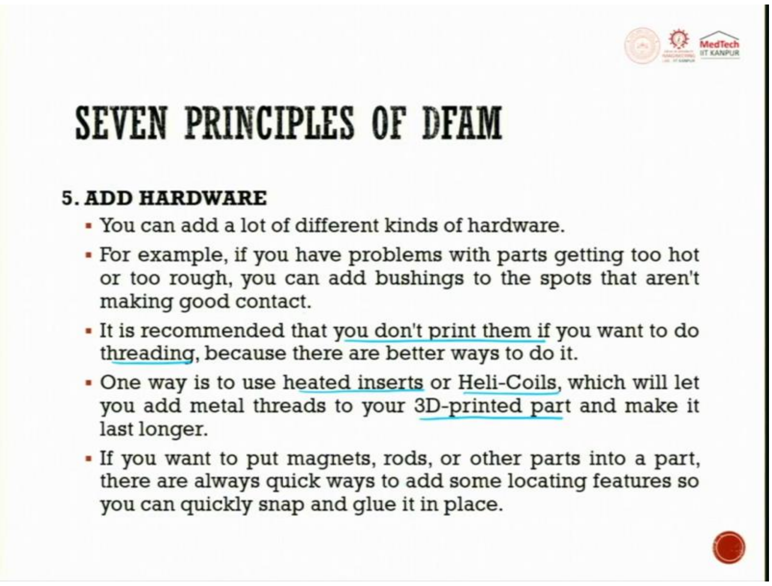

Add hardware. You can add a lot of different kinds of hardware. For example, if you have problems with parts getting too hot or too rough, you can add brushing to the spot that are not making good contact, it is recommended that you do not print them if you want to do threading. Do not print them if you want to do threading, because there are better ways to do it.

One way is to use heated insert or helical coil, which will let you add metal threads to your 3D-printer part and make it last longer. So, here one way of using a heated insert or a helical coil, which will let you add metal threads to your 3D-printed part. If you want to put magnets rods or other parts into your part, there are always quick ways to add some locating features. So, you can quickly snap and glue them at place.

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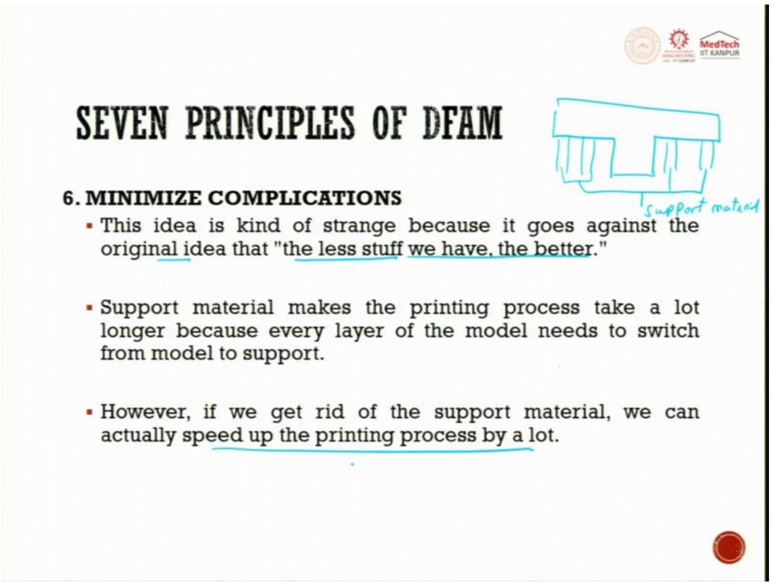

Minimize complications. Wherever best possible try to make the geometry as simple as possible. The idea is kind of strange, because it goes against the original idea that less stuff we have the better. Support materials makes the printing process take a lot longer, because every layer of the model needs to switch from model to support. So, it takes a lot of time.

So, you try to minimize the complications with however, if we get rid of the support material, we can actually speed up the printing process. This is minimizing. So, if you have overhanging like this, so you try to reduce the overhanging so that you do not have supporting material, these are all supporting material. If we get rid of the support material, we can actually speed up the printing process by a lot.

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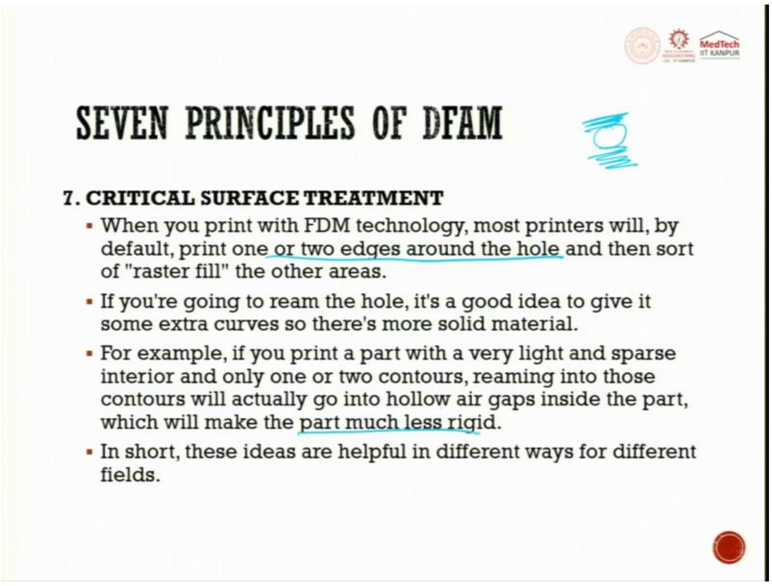

So, critical surface treatment. When you print with FDM technologies, most printers will by default print one or two edges around the hole and then sort of raster fill the other area. Whenever you have a critical default print one or two edges around the hole, and then sort of raster fill the other area. If you are going to ream the hole, it is a good idea to give it some extra curve. So, there is more solid material, because it is going to raster fill it wherever it is, you will have a hole it will be raster filling it.

So, that is what we are saying. If you are going to ream the hole, it is a good idea to give extra curve, so there is more solid material. If you print a part with very light and sparse interior, the only one or two contours, reaming into this contour will actually go into your hollow air gap inside the part, which will make the part much less rigid. These ideas whatever we have seen seven principles are very helpful in different ways in different fields.

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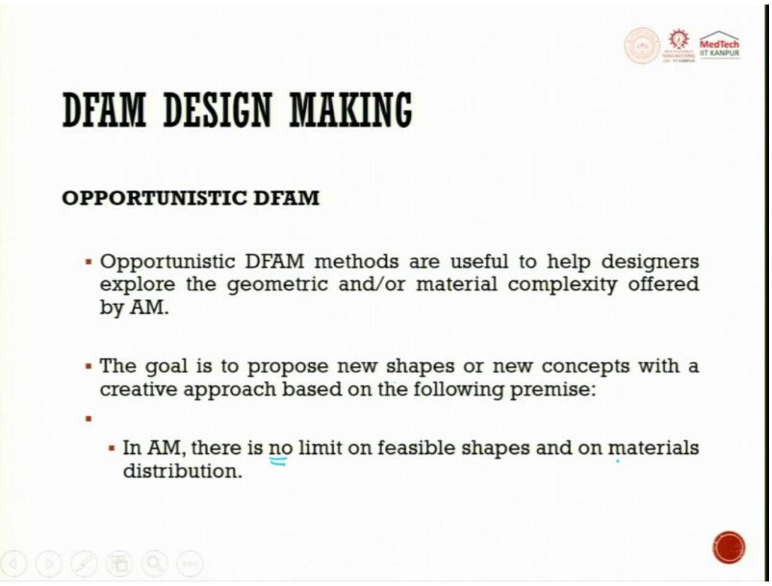

Opportunistic DfAM. Opportunistic DfAM methods are useful to help designers explore the geometric and or material complexity offered by additive manufacturing. The goal is to propose new shapes or new concepts with a creative approach based on the following premises. In AM, there is no limit on feasible shapes and on material distribution. This is called as opportunistic DfAM. So, you have no limitation in size, shape and on material.

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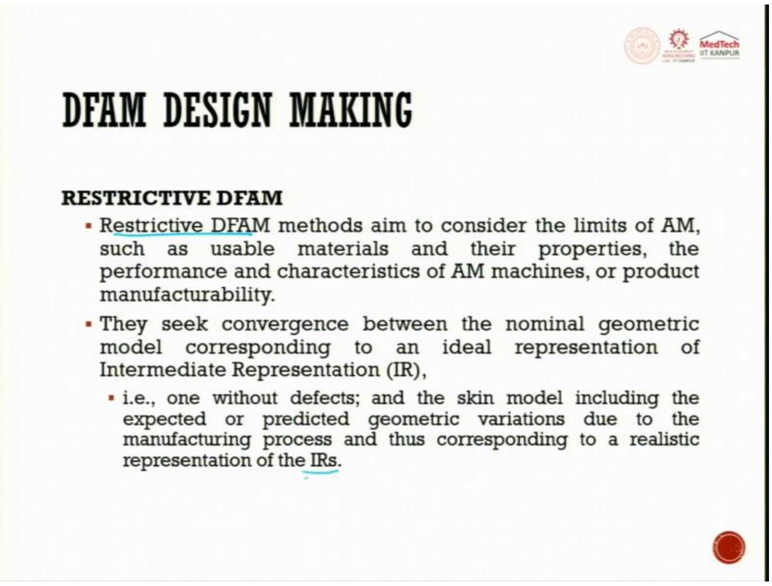

When we try to talk about restrictive DfAM, restrictive DfAM method aims to consider the limits of AM, such as usable material and their properties, the performance and the characteristics of AM machine or product manufacturability. So, this is restricted DfAM. They seek convergence between the nominal geometric model corresponding to an ideal representation of intermediate representation IR. One without defects; and the skin model including the expected or predicted geometric variation due to the manufacturing process and thus corresponding to a realistic representation of the IR.

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The application fields for DfAM are lightweight structures both in aerospace and in automobile sector it can be used. Then part consolidation, parts unification of producing a number of parts into one part. Part consolidation is a field where DfAM can be used. Design that enables different properties from the material of one component is also possible.

Designing that enables different properties from the material of one component is possible. Designing functionally graded material and metal matrix composite material. So, we will see this in detail in the next coming lectures. Medical-specialized design. So, all these areas are areas where DfAM is used for various applications.

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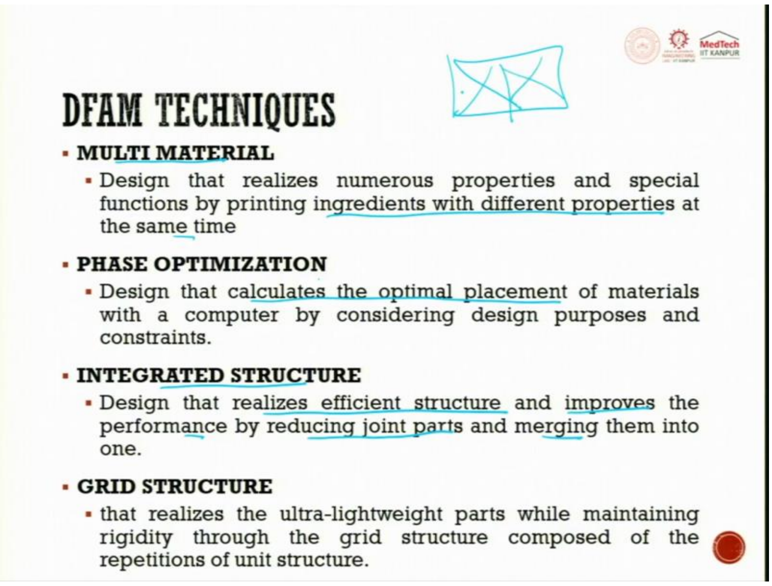

When we talk about DfAM techniques, there are several things which are coming up today. The first thing is multi material. Design that realizes numerous properties and special functions by printing ingredients with different properties at the same time is possible. Multiple material. So, by printing ingredients with different properties at the same time. Next one is phase optimization. Design that calculates the optimal placement of material with a computer by considering design purposes and constraints is phase optimization.

Here, what we do, we would calculate the optimal placement of materials. Next is integrated structure. Designing the realized efficient structure and improve the performance by reducing joint parts and merging them all into one. The grid structure that realizes the ultra-lightweight parts while maintaining rigidity through the grid structure composed of repetition of a unit cell. So, for example, we have this we have unit cell repetition and this can be used for structural load bearing capacity also.

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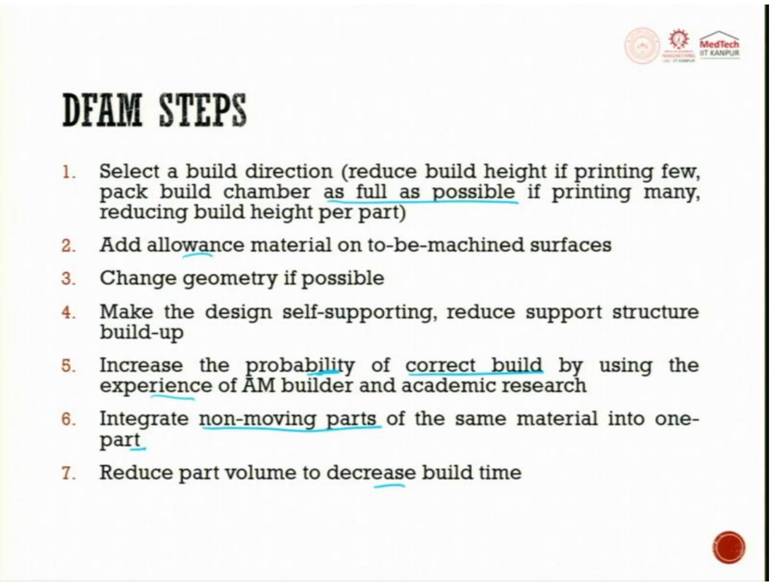

So, what are the DfAM steps which are involved? Select a build direction, reduce the build height if printing few, pack build chamber as full as possible if printing many, reducing build height per part. So, select the orientation of the build. So, this will try to reduce the build height if printing few, pack build chamber as full as possible. So, do not leave ever empty space such that in the table, you try to use all space such that a component can be made.

So, here also we try to use DfAM. Add allowance material on to be machined surface, this is very important. Add allowance, suppose if there is a hole, if the hole is to be maintained at a good surface finish, so, you try to add allowance material on to the machined surface. Change geometry if possible otherwise you allow the same component design to follow. Make the design self-supporting, reduce support structure built up.

Increase the probability of control build by using experience of AM builder and academic researcher, probability of correct build. Integrate nonmoving parts of the same material into one part, that is a very very common thing, nonmoving part integrate all the moving part into one or integrate nonmoving part of the same material into one part. Reduce part volume to decrease the build time.

So, these are some of the guiding principles which we always tell when we are doing design for additive manufactured parts. So, select the build direction, add allowances, change geometry if possible, make the design self-supporting, increase the probability of correct build by using an experience, then integrate the integrating of nonmoving parts together, reduce the part volume to decrease the build time.

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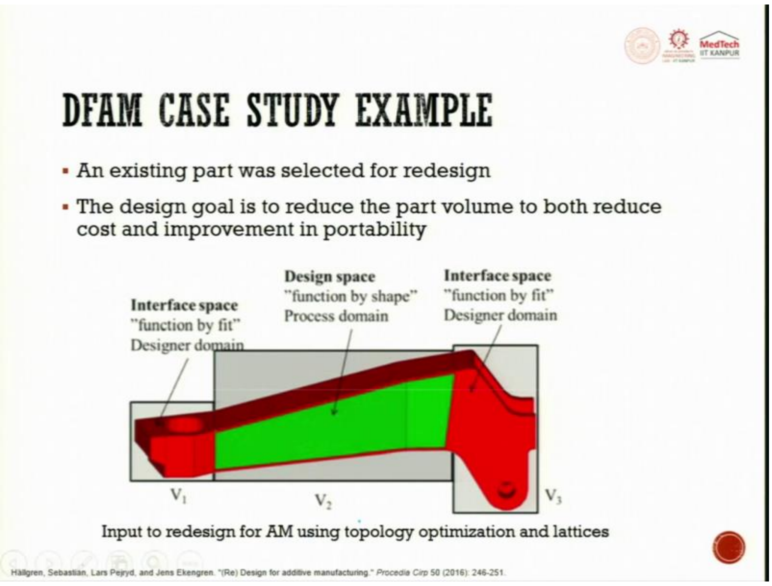

So, let us take a simple case study of DfAM. So, an existing part was selected for redesign. The design goal is to reduce the part volume to both reduce cost and improve in portability. Moment you reduce the weight, the portability increases, moment the weight reduces the cost also reduces. So, here is interfacial space "function by fit" designers' domain. And when you are talking about here it is designed space "function by shape" process domains comes here and interface space "function by fit" the designer's domain comes here. So, here the part has got transformed into additive manufacturable part.

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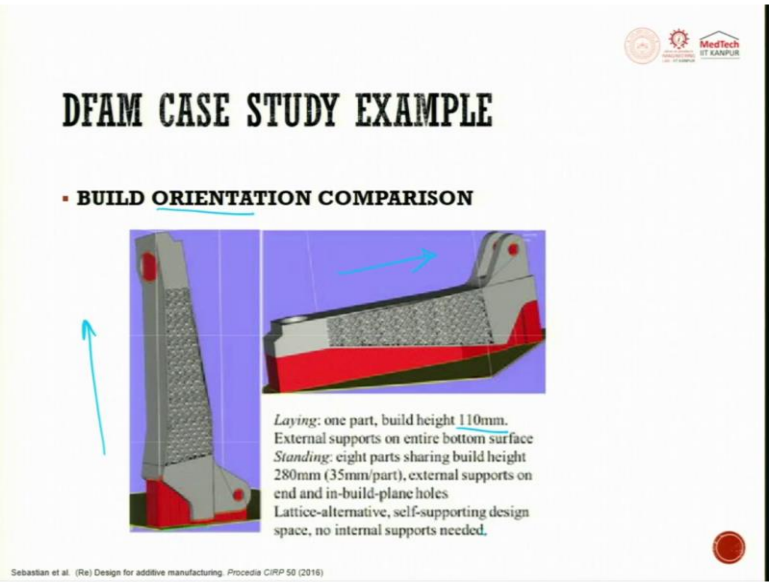

So, the build the orientation comparison. You can build the object like this or you can build the object like this. building the object like this will be faster and it is easy that you have a better control in the microstructure also, but the only thing is when this fellow is rotated, if the load applies between the layer then it damages the component very nicely. So, laying one-part build height of 110-millimeter, external support on the entire bottom surface standing eight parts sharing built height up to 280-millimeter.

The external support on end and the inbuilt plane hole is there. Lattice alternative, self-supporting design space, no internal support needed. So, all these things are put forward and this will build orientation you can compare and try to develop a part.

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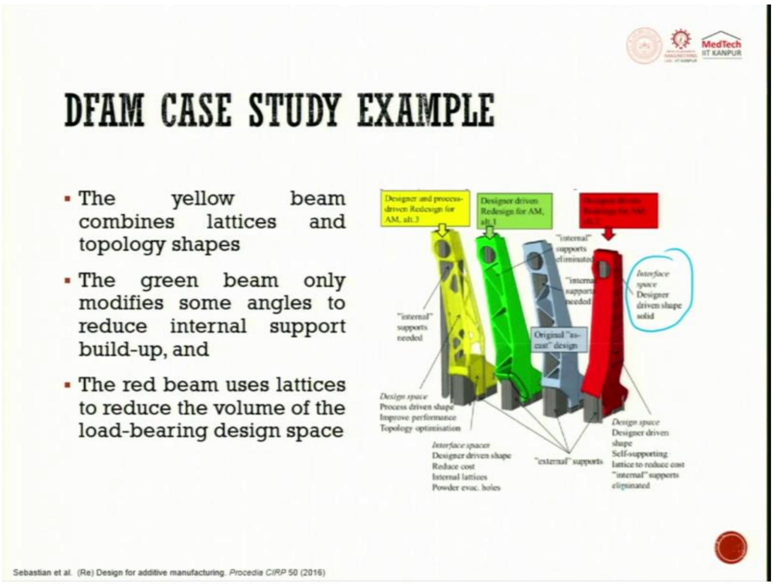

Next one is going to be topology optimization whichever is there. The yellow beam combines lattice and topology shapes. So, the designer and the process driven redesign for additive manufacturing is done here. So, you have internal support for this, all these things are needed and then you have designer space process driven shape improving performance and topology optimization. So, these things are done.

The green beam only modify some angle to reduce the internal support of the built up item. The red one uses lattice to reduce the volume of the load bearing design space. So, you can try to have yellow one, a green one, a red one. So, here the designer in yellow one the designer space process driven shape improves performance and topology optimization in the terms of green. So, you have external support. So, here you will try to have interfacial space the designers driven space reduce costs and internal lattice. When we talk about the red, so, it is the designers driven space field. So, the designer driven shape, self-supporting lattice to reduce the internal support eliminate.

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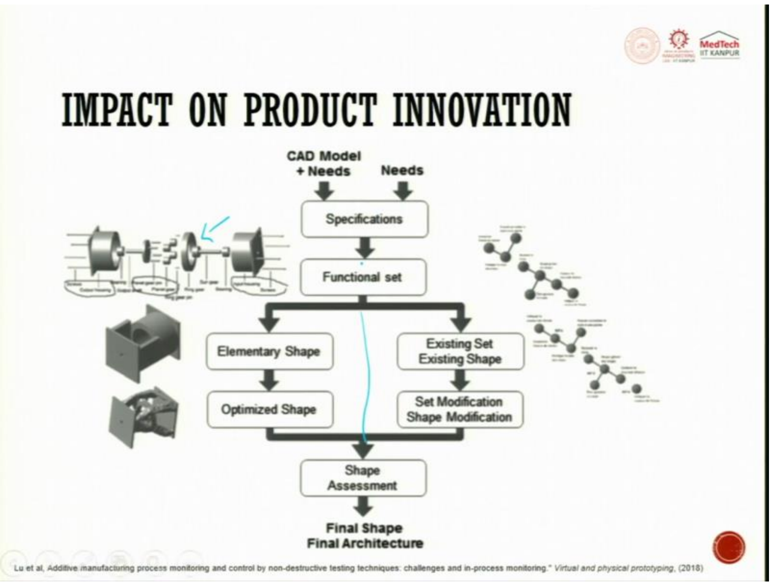

Impact on product innovation with respect to this DfAM. So, you will have a CAD model which is always needed. So, CAD model needs then the other needs then you have a specification then functional set, the functional set is divided into two parts element shape, existing set existing shape, and then you have set modification shape modification, elementary shape and optimization shape is there. So, now, what we get is shape assessments are done, final shape of the final architecture is shown here. So, you can see here the CAD model for this can be developed and that is a need. So, that is added into the specification which moves to the functional test.

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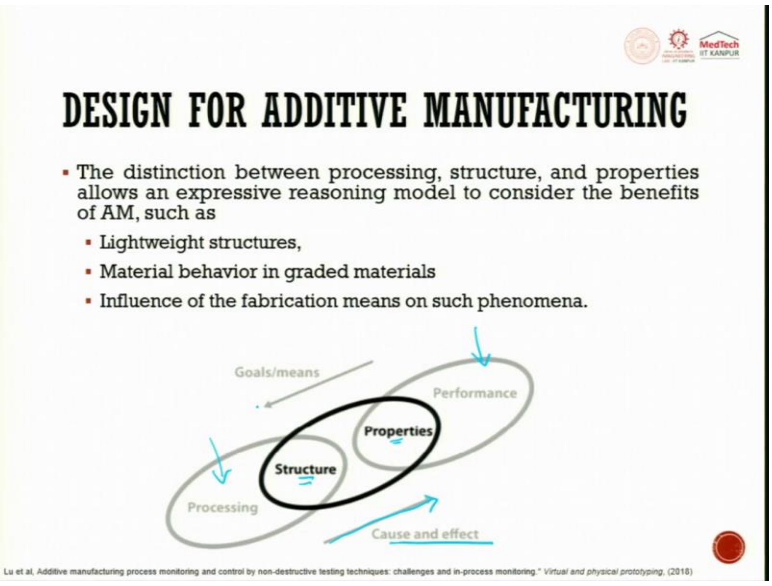

When we talk about design for additive manufacturing, the distinction between processing, structure, properties allows an expressive reasoning model to consider the benefit of AM, lightweight structures, material behavior in graded materials and the influence of fabrication means on such phenomena. So, you have a goal along this direction. And you have a cause and effect began this direction. Cause and Effect, we will try to talk about the cause and how is that influencing the effect of it.

So, you have process, you have structure which is there in the lower gamut, structure and properties in the Union and the last one is performance. So, between processing and performance, you have egg shaped union, which talks about properties and which talks about structure. The goal mean is always in the downward direction, cause and effect in the upward direction.

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DfAM predominantly focus on these five things. One is part consolidation, weight reduction, functional customization, personalization and aesthetics. So, there are other things, but these five are playing a major role in DfAM part consolidation, rate reduction.

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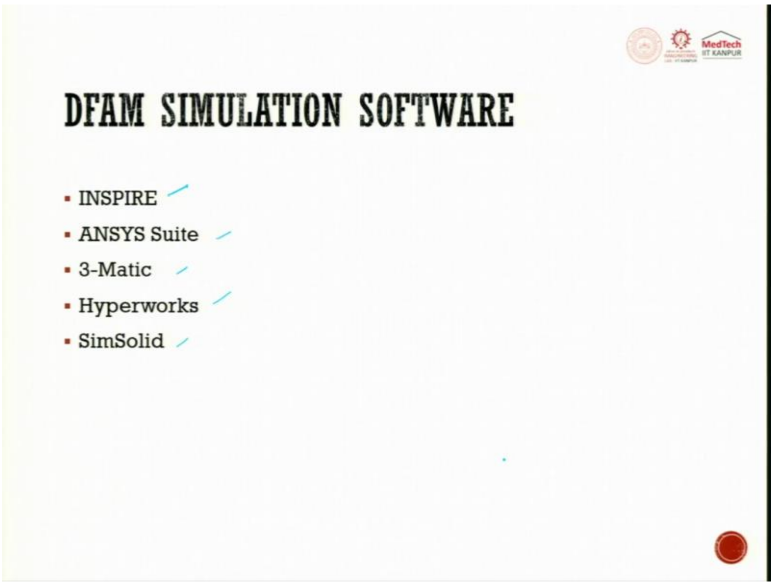

DfAM simulation softwares are many, I have just named few which is INSPIRE, ANSYS Suit, 3D-Matic, Hyperworks and SimSolid. So, these are the most common DfAM simulation softwares which are available today.

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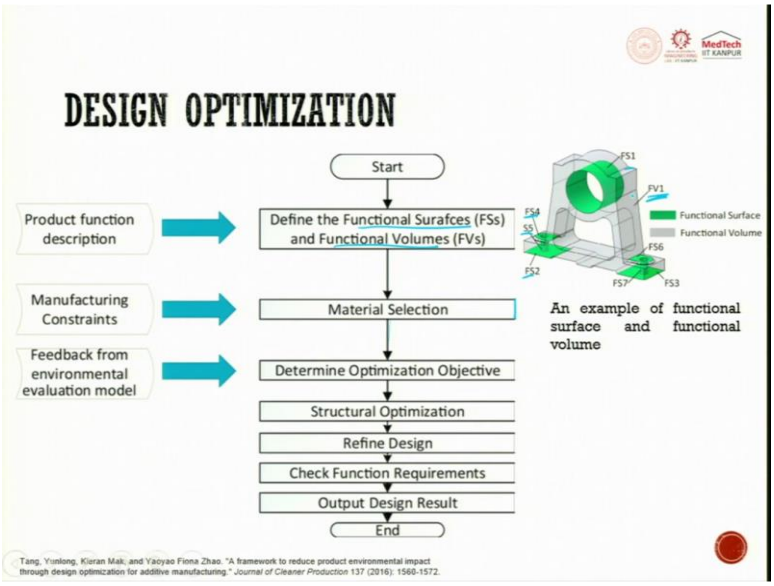

When we talk about design optimization, we start and then we try to have defined the functional surface FS, then the functional volume FV. So, here what we do is we talk about product function description. Next, it goes to material selection, then we try to determine optimization of the objectives, then we will try to look for structural optimization, then redefine design, then check function requirements and the last one is output design result and then you have an end.

So, the functional surface and functional volume is very important, then at the determined optimization objective, you have feedback from the environmental evaluation model is there. So, manufacturing selection material selection, it is always a constraint and then you can do. So, by looking at this object you can try to find out where are the functional surfaces and what are the functional volumes. So, this volume if you further reduce and thin down it might shear while putting into service condition.

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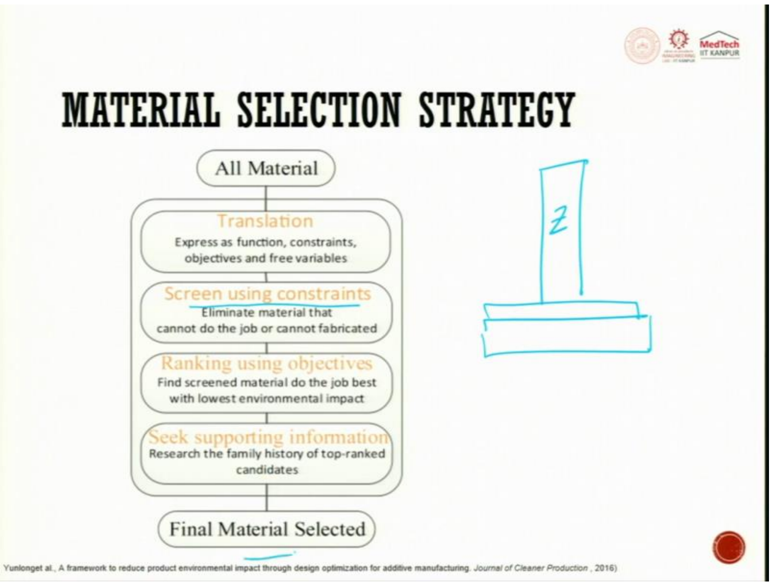

So, material selection strategy all materials are there. So, from there, we first try to do a translation. So, translation means express as function, constraints, objectives and free variables. So, for example, you can try to talk about a shirt which I am wearing. So, it does not depend on the length or some free variable. Or for example, I am trying to construct an object like this, but now the z direction, the z direction has a space as a free variable.

So, express as function constraints, objectives and free variables. Next is screen using constraints, eliminate materials that cannot do the job or cannot be fabricated. So, that is screen using constraints. Then what you do is you rank the function using the objectives what is laid to you. Find screened material, do the job best with lowest environmental impact. So, seek supporting information, research the family history of top ranked candidates and then you start building it.

So, you will have translation, then screen using constraints, rank using objectives, support seeking information. So, all these things are done. And finally, you try to choose a material which is used for the real time application.

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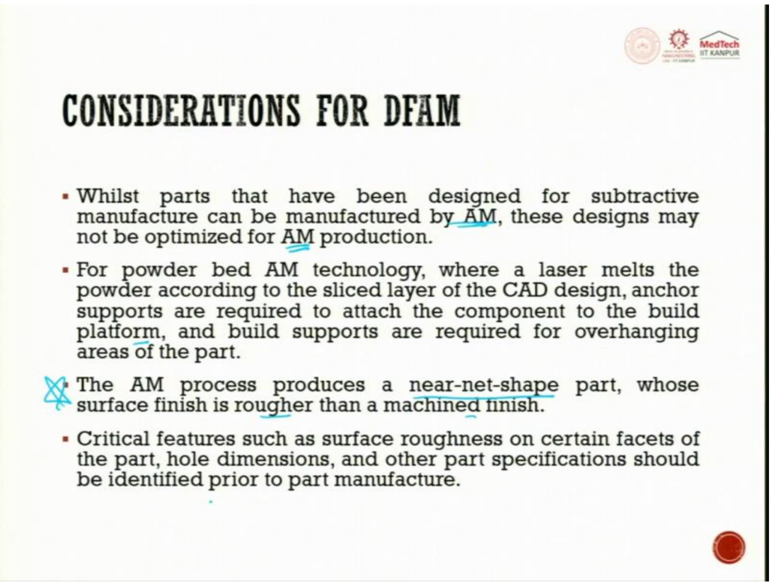

Consideration for DfAM. Whilst parts that have been designed for subtractive manufacturing can be manufactured by additive manufacturing, these designs may be optimized for AM production. For powder bed AM technology, where a laser melts the powder according to the sliced layer of the CAD design, anchor supports are required to attach the component to the build platform, build supports are required for overhanging areas of the part. The AM process produces a near net shape part, whose surface finish is rough than the machined finish.

So, whose part finish is rough than the machined finish. So, this we should understand and we should take it with the word of caution. AM process produces a near net shape part, whose surface finish is rougher than the machined finish. Critical features such as surface roughness on certain facets of the part, hole dimension and other parts specification should be identified prior to the part manufacturing.

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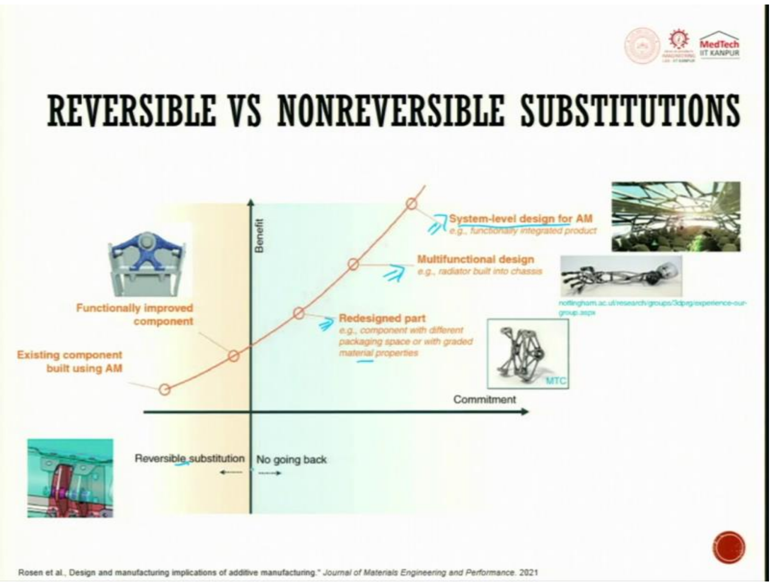

So, here are reversible versus non-reversible substitutions. So, you can see here, these are the benefits, these are reversible substitutions, these are not going back. So, existing components being used in AM. So, this is reversible substitution. Functionally improved components also fall in the reversible substitutions. Then, when you start looking for the redesigning parts. So, they are components with different packaging space or with a graded material properties you have that is redesigning of the parts, then multifunctional design is there.

And finally, what you get is the system level design for additive manufacturing. Today, we are moving in this direction we are now sitting in redesigning the part, then next we will try to develop multifunctional materials and the last holistic system is going to be system level design for additive manufacturing. So, this is an interesting graph where in which we talk about reversible substitution versus no going back.

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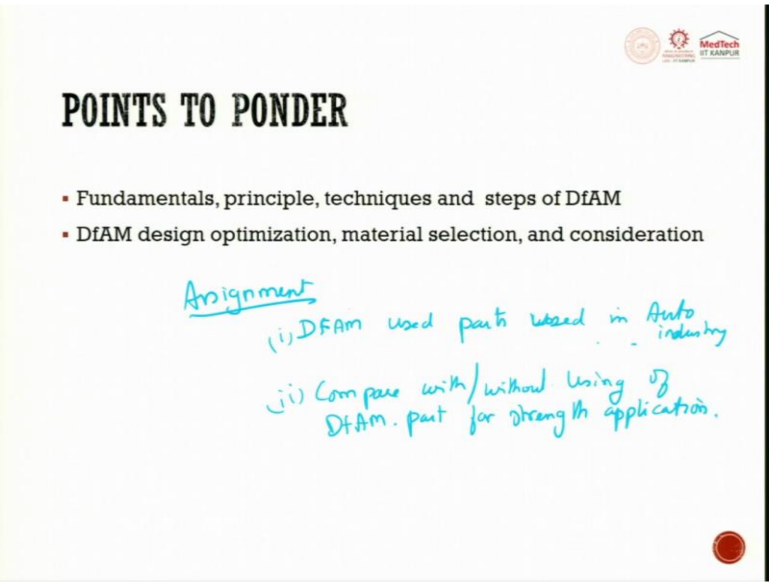

So, points to ponder in this lecture, we went around fundamentals principles, techniques and different steps of DfAM. DfAM design optimization, material selection and consideration are very important. So, after these points to ponder, let us try to have an assignment. So, you will try to compare DfAM used parts used in auto industry, second point, you will try to compare with and without using of DfAM parts for strength application. Thank you very much.