Metal Additive Manufacturing

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Lecture 39

Sustainability in MAM (Part 2 of 3)

Welcome to the second part of the lecture on Sustainability in Metal Additive Manufacturing.

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We have discussed till now, the introduction to sustainability, a brief introduction of what is lifecycle impact analysis that we will take in detail in this lecture. First of all, we will see design quality and sustainability, sustainable design methodology for additive manufacturing, design guidelines that design rules to have a sustainable design and less environmental impact, then additive manufacturing and sustainability in industry for the cradle to grave or the complete lifecycle analysis.

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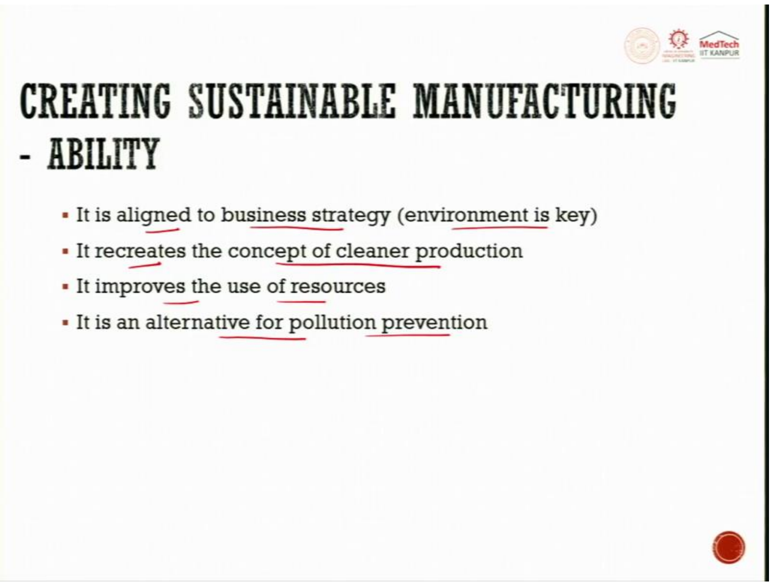

To create a sustainable environment, what is the ability that our system has? It has to have alignment to the business strategy that the environment is the key. This we have seen. We are just recalling what we studied in the previous lecture. It recreates the concept of cleaner production, it improves the use of resources, it is an integrated and systematic approach, it is based upon team effort always.

So, it is an alternative for pollution prevention. Along with this, we need to create a culture that is society is always part of it, the three pillars of the sustainability that we discussed, the cost reduction, overall results, operation focus is there.

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So, there is certain requirements that we have also seen that management support, the resources are required. It needs the implementers, the people who are going to employ this. It needs experts to direct and guide. The needs are to be prioritized that we have seen in the lean and green business model, that value engineering, that environmental value stream has to be taken care of. Then it depends upon the technology access, the Lean environment integration.

So, it may also suffer from environmental differences worldwide. It may suffer from cultural differences, but overall goal globally and locally has to be green and sustainable system.

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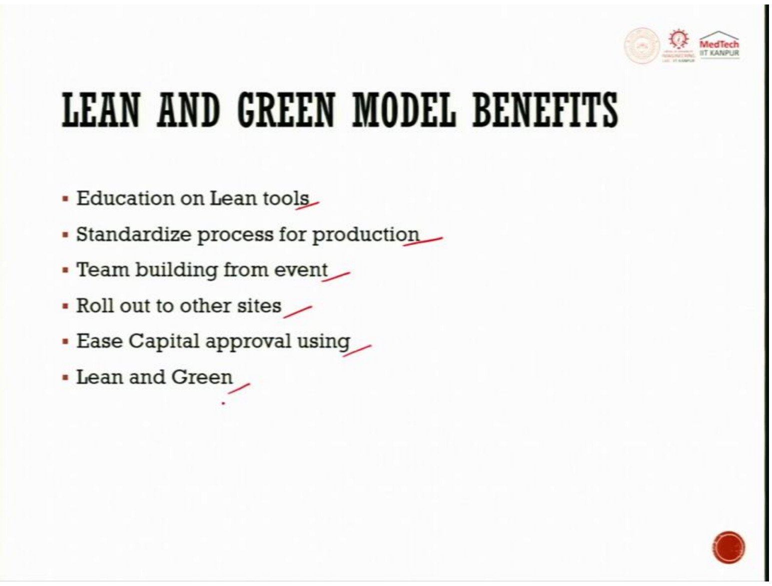

Now, if we try to see the benefits, education on Lean tools, then standardized process for production, team building from the event, roll out to other sites, ease capital approval using and Lean and Green systems are obtained.

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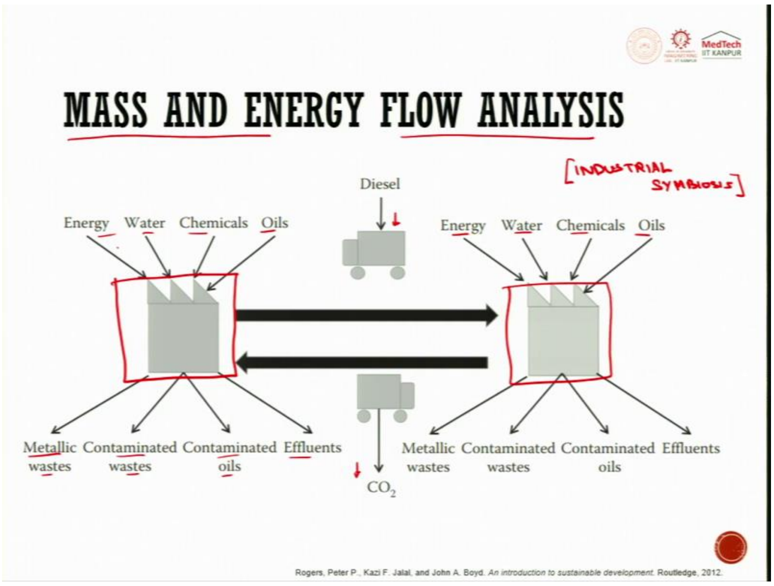

Now mass and energy flow analyses are very important to understand, how our system is working. So, this is a system in which there are certain inputs which are coming - energy, water, chemicals, oils. These are from the management viewpoint, we can have the three M's of management man, money, material. What we are getting out are metallic waste, contaminated waste, contaminated oil and effluents.

Now, this system is interacting with another system, where flow analysis is going on that is still again consuming the same resources or similar kinds of resources. And it is also producing a similar kind of the waste here. I am only talking about waste, these wastes metallic, contaminated waste, oils, effluents or emissions, then we have energy, then we have new job design, this all comes out.

So, in between when the transportation between these two systems also happen there is consumption of another resource that is diesel, and we also produce carbon dioxide. So, what mass and flow energy analysis tries to study is, how do two systems interact with each other? And can we have the systems, which are working together? So, can we use the waste of one system as the resource for the other system?

So, this is known as industrial symbiosis. This is how we need to understand, the systems keep on going. To understand this, how do the systems could help each other, industrial symbiosis though is one of the methods or one of the concepts that could be instituted, but we need to understand in a broader concept in the broader viewpoint, what is circular economy?

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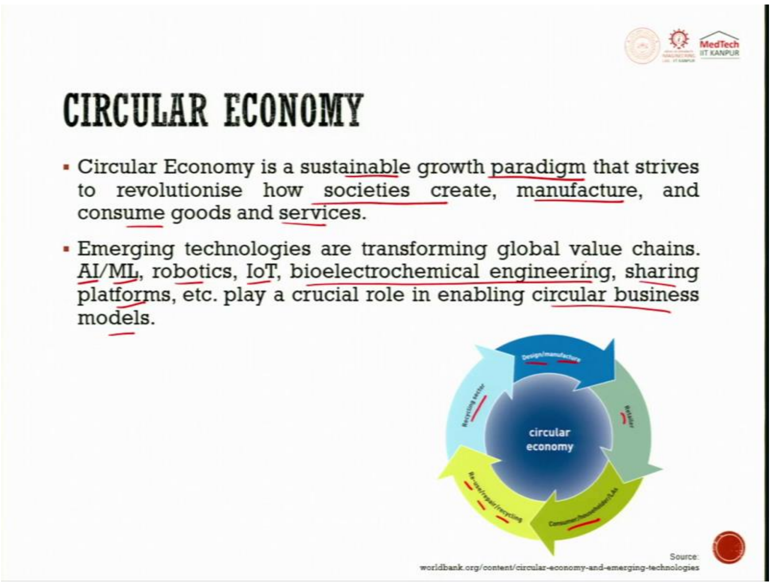

Circular Economy is a sustainable growth paradigm. Paradigm that means it is a situation, design, a change that strives to revolutionize how societies create, manufacture and consume goods and services. So, emerging technologies are transforming global value chains. So, artificial intelligence, machine learning, robotics, Internet of Things, bio-electrochemical engineering, sharing platforms et cetera play a crucial role in enabling circular business models.

In a circular business model, you could see along with the reuse, repair, recycling, that the recycling sector is in itself also interacting with the design and manufacture. And the retailer, the consumers all are just moving around the circular economy are trying to connect to each other. So, how does this connect with the sustainable engineering or sustainable development?

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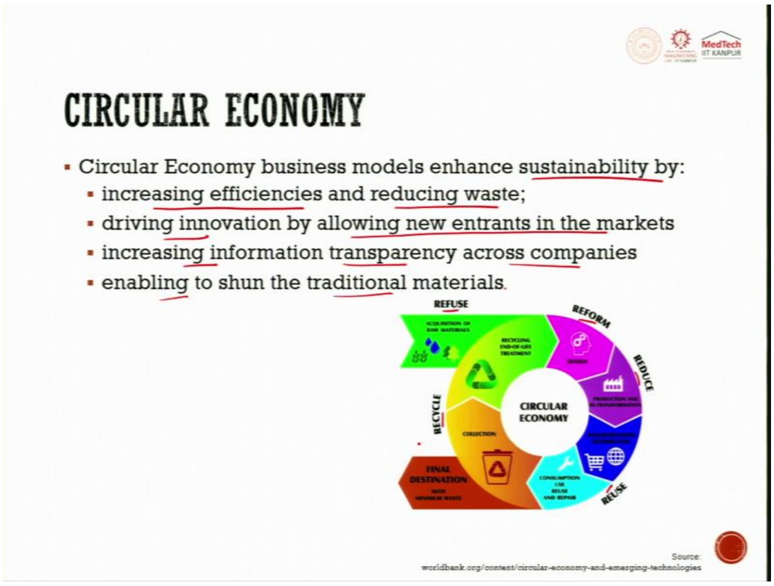

Circular economy business model enhances sustainability by increasing efficiencies and reducing waste, that is the drive old models in which we increase the efficiency and driving innovation by allowing new entrants in the market. Increasing the information transparency across companies, enabling to shun the traditional materials or traditional processes, which are consuming more energy or which are non-biodegradable.

So, refuse, reform, reduce, reuse, recycle, we saw in the solar cyclic diagram that reuse, re-manufacture, recycle were only three resorts. Before even reusing, we could reform. Before even reforming, we could refuse to use the material or something that is detrimental, that is not having great influence on the sustainability.

So, this is how it goes acquisition of raw materials, then recycling of end-of-life treatment, that design production and retransformation, transformation and distribution, consumption use, reuse, repair. Collection of the material, this is also very important. When we collect the material, sometimes the energy consumed or an energy that is instituted in collecting the material or putting the waste in the last stage that is also higher.

We will see the comparison between the energy that is consumed in different kinds of the materials in additive manufacturing in the forthcoming slides.

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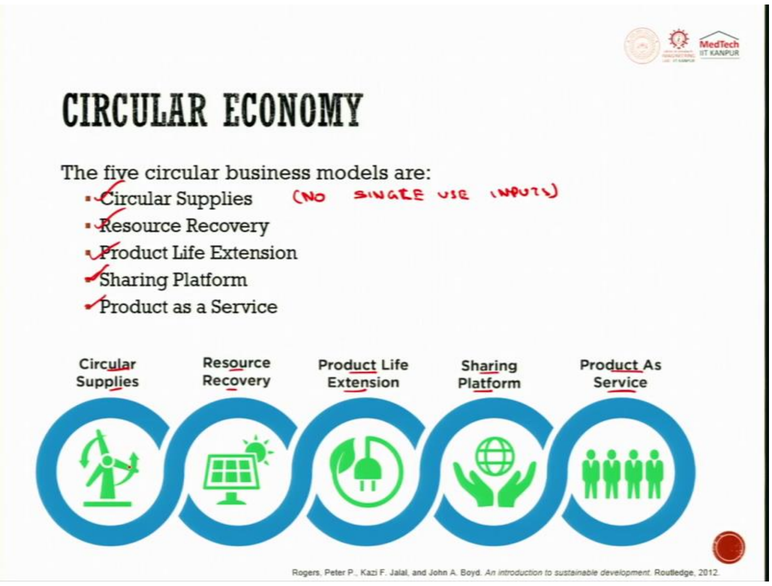

The five business models that the part of the circular economy are number one, circular supplies, number two, resource recovery, product lifecycle extension, sharing platforms and product as a service. A circular supplies, these supplies as far as possible are to be renewable, if not renewable, recyclable input and no single use inputs are allowed. I will put it here, no single use. It is suggested in a circular economy.

Then resource recovery, that is reusing the waste material and try to minimize using the fresh material that is resource recovery. Then product life extension. Life extension means repair, reuse, upgrade, resell all these things comes in the product life extension. So, we try to use the powder again. We try to use the material. We try to use the same plate over which the previous product or the previous components was developed.

We cleaned that plate. This is product life extension. The sharing the platform that is a collective use and when we try to put the multiple components into a single bed and tried to produce that in a single go, can we have in metal additive manufacturing? can we print multiple components in a single go, in a single print, which are of similar shapes?

Generally, in subtractive manufacturing the components which are of similar shapes, like all the circular components, all the holes or all the rectilinear components would be produced together using a similar kind of the CNC program. This is known as group technology. In additive manufacturing, we can produce a circular component, a complex carburetors system, an impeller all in one bed.

This is how sharing the platform is more easy in metal additive manufacturing or additive manufacturing in general. So, collective use access all these, boosts the usability of the system and like the energy consumption maximum in the fluids deposition modeling is in the sintering process, because it is a furnace.

So, furnace if it is working in the full capacity, definitely the energy consumption would be divided by the number of the components and the overall energy component, energy consumption per kg of the product produced would be minimized. This is how we tried to use this. Now product as a service is one of all the models that circular economy also suggests, that is convert your product sales to service models where the product retains the ownership. So, that you can keep on providing the product time and again.

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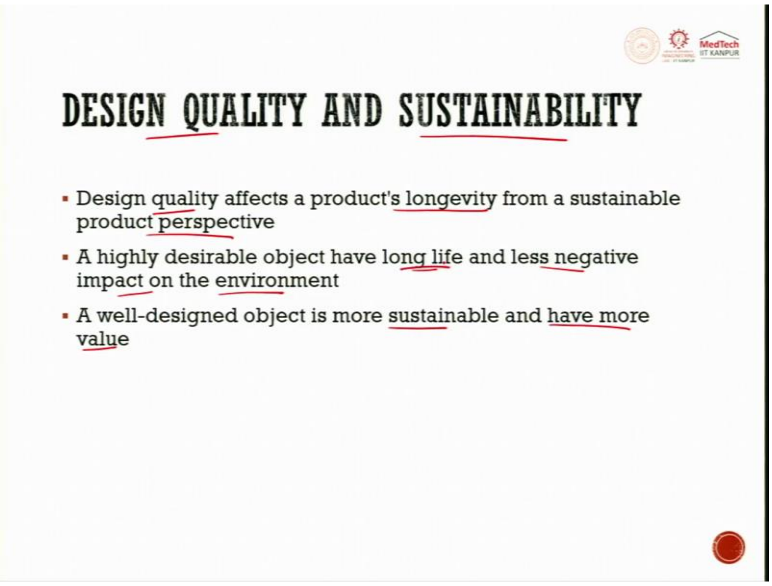

Let us have a quick look on the design quality and sustainability. Design quality affects a products longevity from a sustainable product perspective. A highly desirable object have long life and less negative impact on the environment. A well-designed product or well-designed object is more sustainable and have more value, that is the time we invest to optimize the topology; time we invest to design, it is always beneficial to have more value in the terms of the greenness in the product.

The design quality includes the product's technical quality, desirability, the joy of use, that is a fit or the tolerances that we have provided, it has to be exact according to the requirement. A user attachment that designers may boost desirability by making it look better, by tailoring it to user needs exactly. So, a highly desirable object has a longer life as it is said here.

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Now additive manufacturing of a titanium bottle opener as an example here, if you could see. This saved 90 percent of the material compared to a CNC machining because the material which was there in the subtractive manufacturing, so, there is no material in between just having the proper optimized material only wherever the stress concentration is more, it is designed accordingly.

So, it would have the similar strength, similar performance as it could have been there with the CNC manufacture component and we have saved 90 percent of the material. So, this is additively manufactured titanium portal opener. It was made out of titanium 64 utilizing selective laser melting SLS or SLM process to remove as much material as feasible, while keeping mechanical properties intact.

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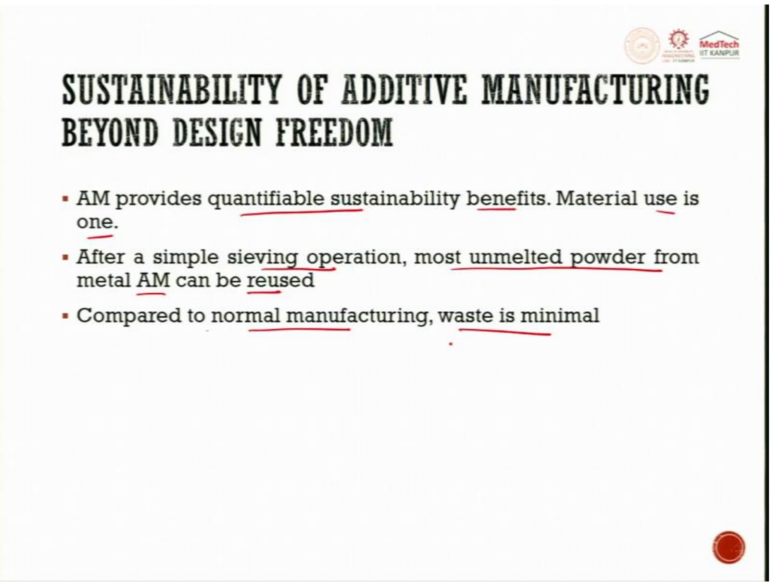

Sustainability of additive manufacturing beyond design freedom. what do we have? It provides quantifiable sustainable benefits. Material use is one of those only. Other than this, we have simple sieving operation, that is most unmelted powder from the additive manufacturing can be reused. Compared to normal manufacturing, the waste is minimal. So, there is a general flow for the design of additive manufacturing.

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The whole design workflow can be divided into four major stages that is a functional stage, design optimization, design refinement, environmental impact evaluation.

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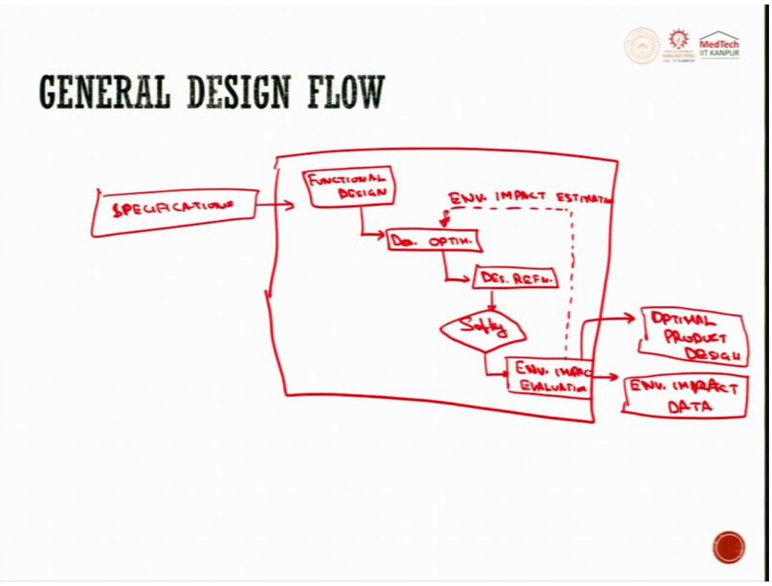

If I try to see these stages, so how does it go? So, we have the specifications as the input. This is a general flow or we have designed requirements or specifications, these goals as an input to my manufacturing system or my design system. So, where functional design is there and we have physical entities, which enter to the design optimization, so which further provides that design refinement and then we have the diamond box, which says that the safety of all functions is put or not.

This is a general flow, safety, yes or no? Then we have the environmental impact evaluation. Now, how does environmental impact evaluation is connected to this safety and after safety, how does it also go? During design optimization itself, the environmental impact has to give its inputs. So, I put a dotted line, that is a feedback, has to be taken from the environmental bed.

So, arrow goes in the reverse direction, so this is the environment impact estimation that goes or that is taken care into the design phase only impact estimation, environmental impact estimation. Now this gives us the output now, that output is our optimal product design or the product, yes, two inputs I could put here.

One is the optimal product design and we have environmental impact data to have the environment in the back analysis and optimal product design. So, this is a general design flow, when we take into account in the framework the sustainable design.

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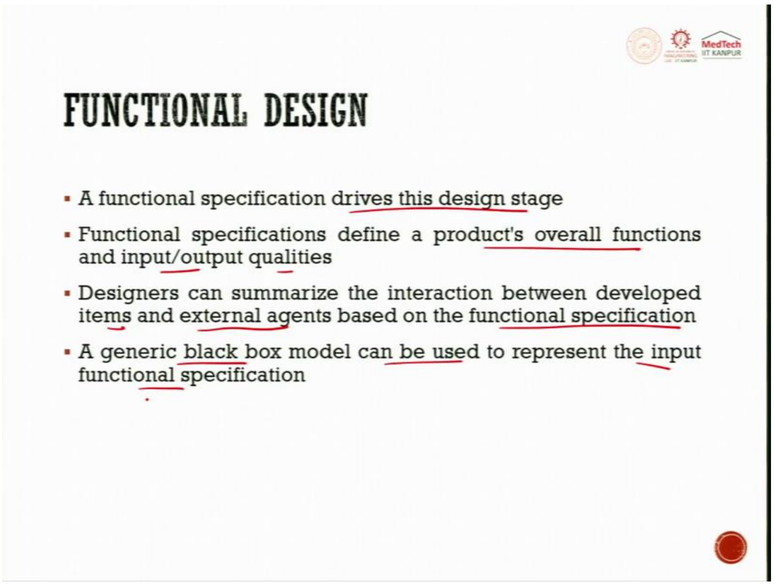

Now, next step in this is how does this derive the design stage? A functional specification drives this design stage. The function specifications define a product's overall functions and input and output qualities. The designers can summarize the interaction between the developed items and external agents based upon the functional specification. When I say functional specification like for example, this bottle opener, the function was just to open the bottle, number one primary function.

Secondary function, it has to be held in the hand. So, length has to be accordingly. Number three, the size has to be so design, it has to be held ergonomically. For example, the size of the pen. It is generally the 10mm width of the pen. Similarly, 10 mm by 10 mm square has to be there. So, the outer edges have to be accordingly. So, these are the functions. The function of the material which is not there that was not required.

So, those are all taken off. Similarly, the function of a chair can be just to support the body the top surface of the chair is only required. The basic supports, the cross that we have to plug the legs those are all support functions to make sure that the load that is put on the chair. For example, 100 kg is supported. To support that 100 kg load, what else designs could be put, so those are already taken care of, while we design for sustainability. A generic black box model can be used to represent the input of the functional requirement.

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Next, we have the general black box for the product functional specification, to design flow of functional design stages. So, there could be different functional design stages, models as well that could also be put. That could only start from the functional decomposition, then function mapping, then building physical entities, then physical integration and then working on the physical entities only that could also be one of the part.

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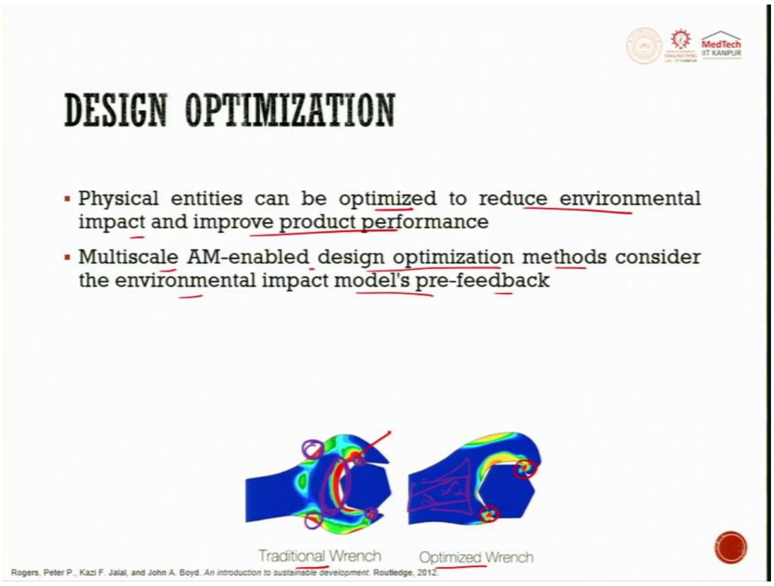

Next is design optimization for sustainability. Though we have discussed and study design optimization at stretch in the previous lecture, still, I would like to mention here that physical entities can be optimized to reduce environmental impact and improve product performance.

Multiscale additive manufacturing enables design optimization methods, consider the environmental impact models as pre-feedback. So, functional needs and manufacturing restrictions become design parameter constraints here.

Additive manufacturing enables the design optimization approach and it can be selected to optimize the creative physical entity on multiple designs case. For example, a traditional wrench and optimized wrench. A traditional wrench, you can see how the load is distributed and we have maximum this red area, how the load is distributed around this red area only.

In an optimized wrench only at small points the load is distributed. So, this is how the function is to hold the nut to provide enough strength to the nut or the head of the nut or bolt. So, as we can rotate it, we can open it. So, traditional wrench is designed in this way. Optimized wrench has a design in which the strength of the material is more.

So, even when this material this portion if you see, if it is not even in the contact to the nut, but still it is facing equivalent force as it is faced at the contact points. These two are the contact points here. Even this area is having extreme stress concentration here. So, this is a new design that could be used. Similarly, in this design itself if suppose material is not required here. It could also be produced in the form of mesh. Right here a mesh could be produced. So, this is design optimization.

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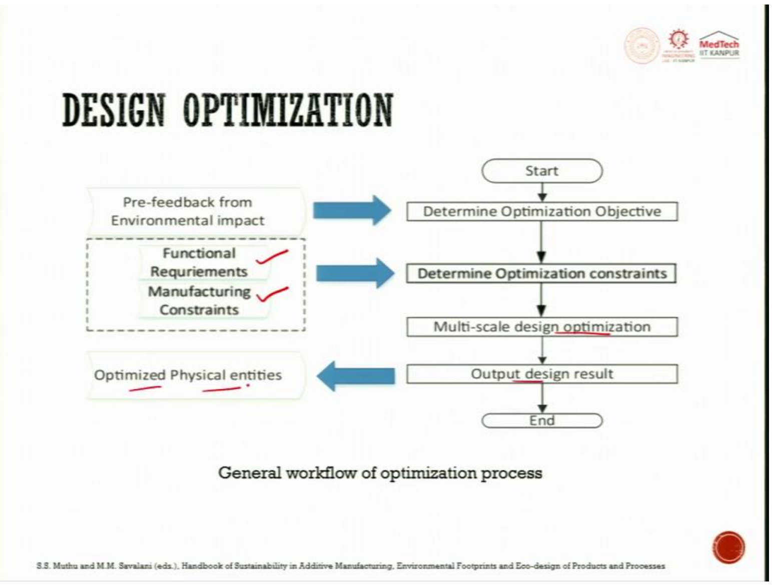

In the design optimization, the pre-feedback from environment is taken that acts as an impact input. This is how the workflow of optimization goes. So, this goes as input and that determines the optimization objective in the flowchart.

Then to determine the optimization constraints, the functional requirements and manufacturing constraints both play a major role and this is put in a dotted box because this is in itself a big system or big set of parameters play a role in it. Then multiscale design optimization is taken place, then output design results give us the optimized physical entities. This is how a general workflow goes.

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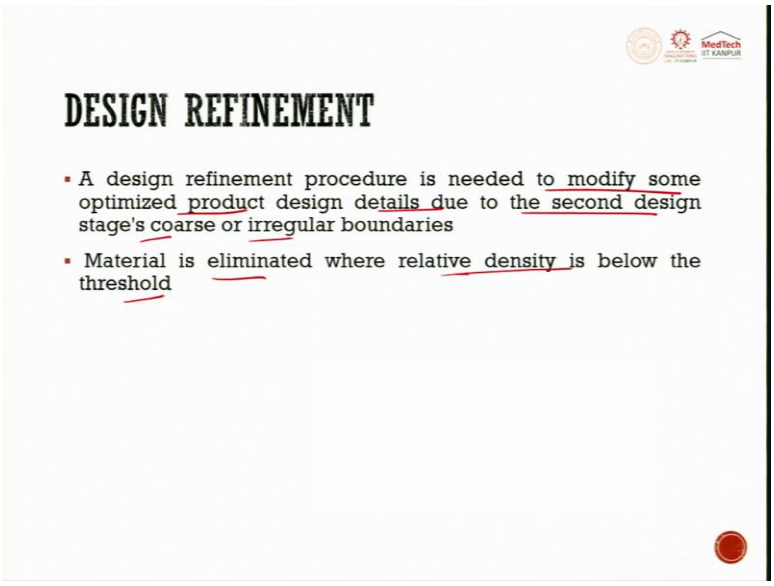

Then design refinement is one of the steps, always. When we have gotten a design in the previous flowchart, we tried to refine the design as well. So, its design refinement procedure is needed to modify some optimized product design details due to the second design stage's coarse or irregular boundaries. Material is eliminated, whether relative density is below the threshold as we have seen in the example of the bottle cap opener.

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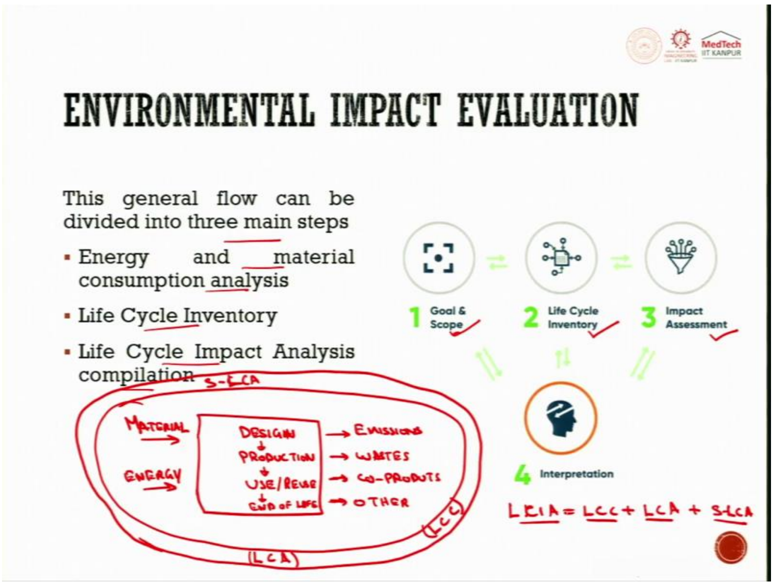

In the environmental impact evaluation, the general flow that can be divided into three main steps as it is given here, the energy and material consumption analysis, the life cycle inventory, a lifecycle impact analysis compilation. For that we need to identify our goal and scope of the analysis or the assessment that we are going to do, we need to understand the lifecycle inventory of the component or the product under study.

The impact assessment, this would only give the interpretation. So, majorly if I put a manufacturing system here, so, it has inputs as material and energy. So, this is a manufacturing system that takes raw material, it works on the system, which I will put steps here I would put it designs. Then it goes for material-preparation or I would say production. Then we use and maintain, then the post processing everything happens.

Then we use or reuse again. Then I will put, end of life. Then the material is over. This is a system of the life of the product that is under study. In this the outputs that would come that could be our indicator, that has to be calculated which could be emissions. Then it is the warehouse wastes that is a solid waste.

Then we have co-products or I could say byproducts even that could be used by another industry then other releases, any other releases such as the material, water wastage and so. So, in this overall system, if suppose if I put it into a circle, the overall system the boundary of the circle, that would give me the lifecycle impact analysis is given here, it would have energy and material consumption analysis, I call it Life Cycle Assessment, LCA as number one.

Number two, the costing, the life cycle costing is number two.

LCIA = LCC + LCA + SLCA

There are models suggested by some researchers it was also given in the previous course on sustainability in manufacturing systems. You can also have a look over it if you wish to go for the deep in this.

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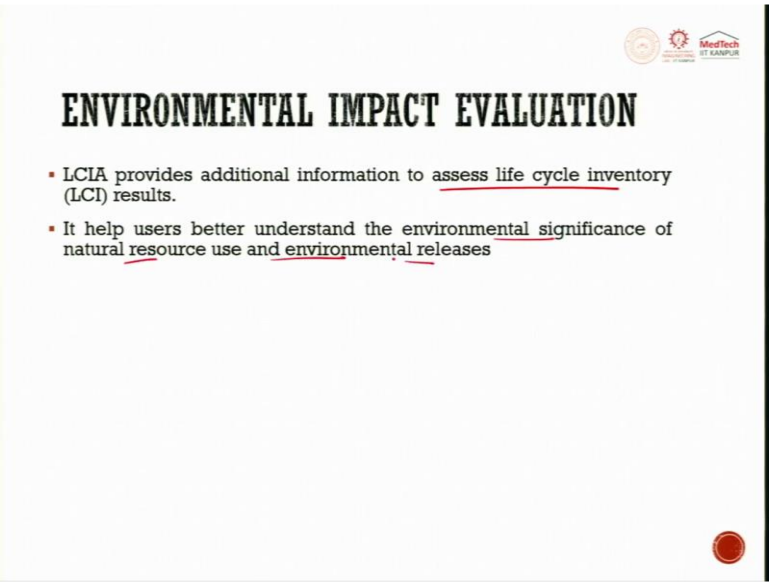

Now the lifecycle impact analysis provides additional information to access life cycle inventory. It helps users to better understand the environmental significance of the natural resource and environmental releases. So, this is how it helps.

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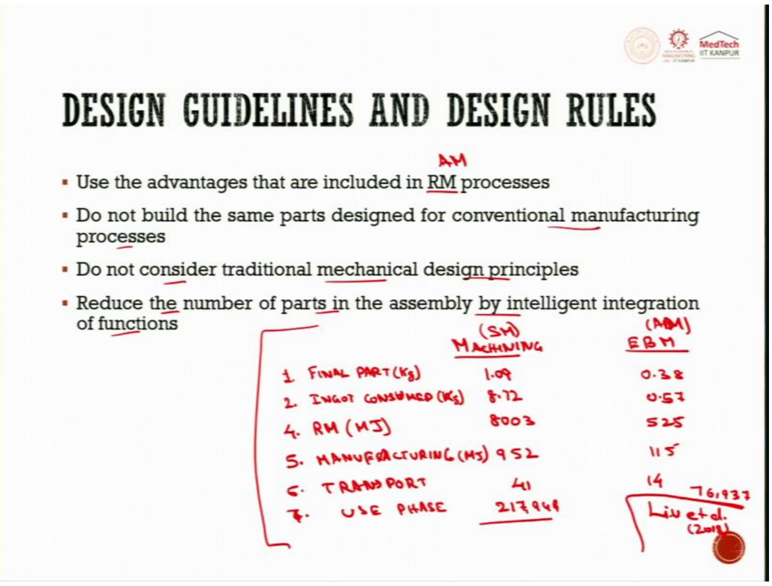

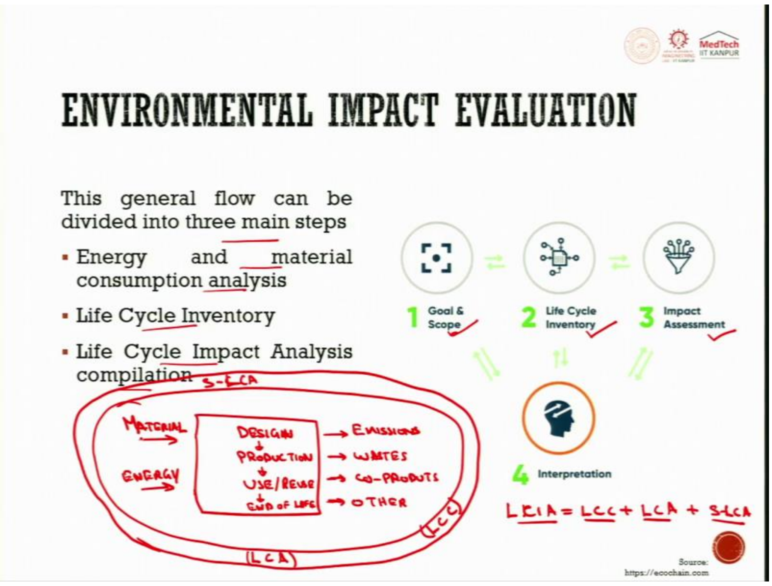

The certain design guidelines and design rules which are to be taken care of when we are trying to design in additive manufacturing. So, use the advantages that are included in the RM processes that is metal additive manufacturing processes or additive manufacturing processes, that is the interchangeable term here.

Do not build the same path design for conventional manufacturing processes. Do not consider traditional mechanical design principles. Reduce the number of parts in the assembly by intelligent integration of the functions. Let us check whether there are bionic examples to fit your tasks, whether these give good hint toward better solutions?

Then, once you have good design freedom always. Then we have a great design freedom in additive manufacturing, it is no longer difficult to produce big parts. Then we optimize the design towards highest and lowest weight. We use undercut, hollow structure. These are not useful. We should not think about tooling because this is no longer needed at all in additive manufacturing.

So, if I suppose tried to compare additive manufacturing with a subtractive one, I would like to put the energy consumption that is taken from aresearch by Liu et al. I will put the reference here Liu et al in 2018. And their research published in the procedure manufacturing on energy consumption in additive manufacturing those metal parts give this data that for machining and for the additive manufacturing.

A machining is my subtractive manufacturing, I put one add additive manufacturing process that is taken by the study is the electron beam manufacturing. This is subtractive manufacturing, this is additive manufacturing. And these steps in developing a product and the parameters that they have taken that is the final part, the weight of the final part, this first parameter in kg in machining was 1.09.

And for the electron beam process, you could see the wastage of the material is minimum and overall component that is produced is also of around one third of the weight of the part that is produced in conventional manufacturing. Number one, the material that is removed. So, generally material becomes half of the size that we get the original ingot. So, the final part that we have got is of 1.09 kgs and here in EBM it is 0.38 kgs only.

So, let us also see that they have given the ingot that they have taken the weight of that how they have given it here. The more shocking data we will have when we see the weight of the raw material, this is one third of the output product that we have got around one third of this, but the input material that is the ingot consumed again in kg it was 8.72 kgs in machining and 0.57 kg only in electron beam processes that is additive manufacturing.

Now, the weight is reduced in terms of material that we saw it majorly two inputs here material and energy from the material we point this wins, additive manufacturing wins here. It is about 20 times the weight of the additive manufacturing, their subtractive manufacturing is consuming. Now, let us have a comparison on the energy consumed in developing the raw material.

In the raw material extraction, there is energy embodied in it. When we extract the material, we process the material. So, this is also put. It is going to be definitely proportional to the weight of the material. So, in the raw material I have put energy in mega joules, it is given as 8003 mega joules of energy and 525 mega joules in subtractive additive manufacturing respectively.

Then we have the manufacturing energy, the energy consumed in the manufacturing. This is also in mega joules. In subtractive manufacturing it is given as 952, in additive it is 115 mega joules respectively. Then in transport and use phase, the energies are given for the component or the product they have studied since the transport itself it is 41.

This one is 14, the use phase it is showing 217949 and this one is showing 76937 to see the overall energy consumption in additive manufacturing that is studied by Liu et al in 2018 is far less than the counterpart produced in a subtractive manufacturing. This finishes the second part on the lecture series on sustainability in metal additive manufacturing. I will talk about the lifecycle stages in the third part. Thank you.