

**The Future of Manufacturing Business: Role of Additive Manufacturing**  
**Mr. Ajeseun Jimo (University of Nottingham)**  
**Department of Management Studies**  
**Indian Institute of Technology-Madras**

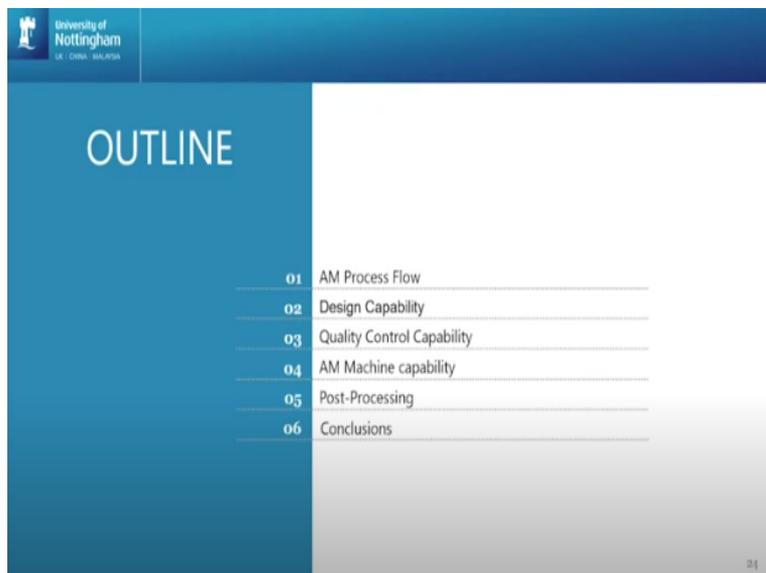
**Lecture – 14**  
**AM Implementation and SC Configuration - II**

**(Refer Slide Time: 00:15)**



Hello everyone, you are welcome to this second session on additive manufacturing, implementation and supply chain configuration. As I said earlier, this section will focus on some of the empirical findings that have emerged from our research over the past couple of years. We would be focusing on the implementation factors associated with supply chain configuration in metal additive manufacturing.

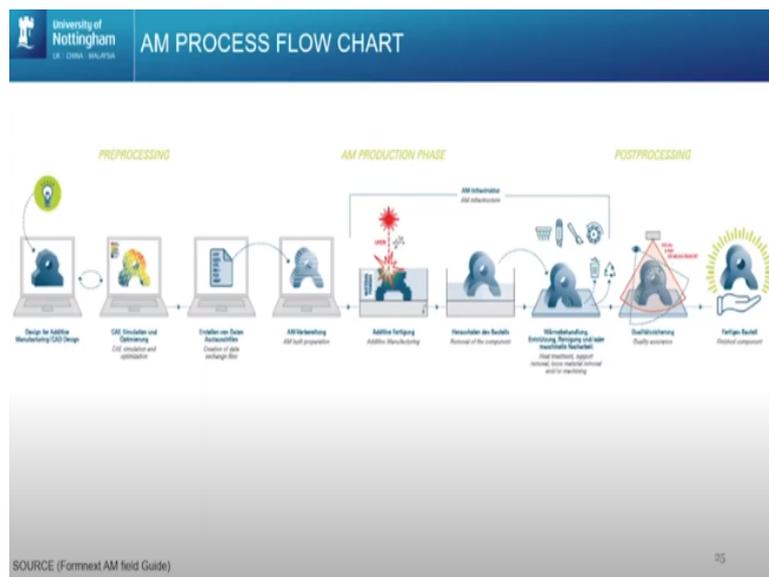
**(Refer Slide Time: 00:56)**



I will start by describing a process flow, a generic process flow diagram for additive manufacturing supply chains. This process flow diagram is applicable to all additive manufacturing processes. But for our purposes in this presentation, we will be focusing on powder bed fusion processes and as I mentioned earlier, the selective laser melting and the electron beam melting processes are the dominant processes in the metal space as we speak.

But things might change in the future. Because it is a constantly evolving landscape. So, I will be highlighting the implementation factors associated with four decision areas. First of all, I will talk about the design capability, subsequently the quality control and the machine capability. I will be talking about post processing with the implications for supply chain configuration and especially with regards to distributed manufacturing.

**(Refer Slide Time: 02:21)**



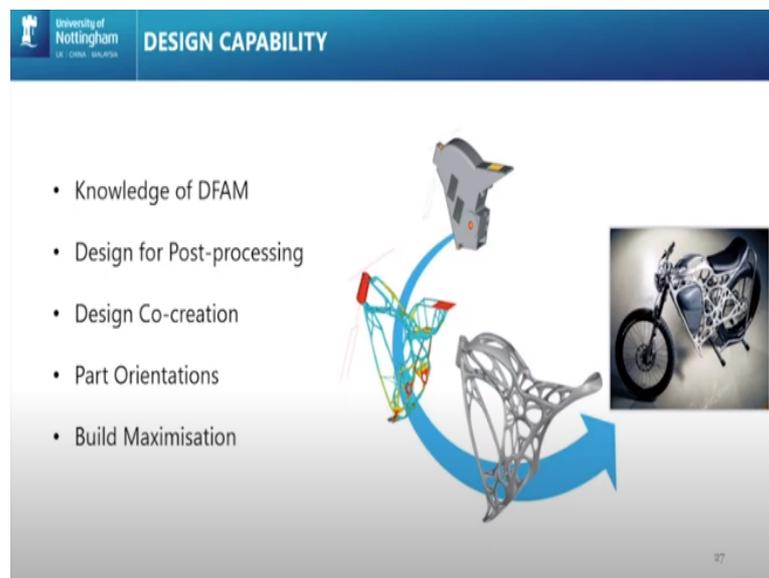
So, the generic process flow for additive manufacturing consists of three salient phases. The first phase is the preprocessing stage and we may divide the stage further into two stages. I am talking about the design stage and the build preparation stage. Subsequently, there is the AM production phase or the manufacturing phase.

As you can see on the screen, this is where the actual manufacturing or the actual build takes place in your build platform, depending on which process you are using, whether it is EBM or SLM in this case. Subsequently, you have the post processing

stages, which may involve one form of support removal or heat treatment, or some finishing process, depending on the requirements of your end application.

Lastly, there is the inspection phase to actually verify and validate the quality of your part and this you know varies according to industry sector.

**(Refer Slide Time: 03:47)**



So, let us talk about the first phase. Let us talk about design. This is absolutely crucial and central to the success of the viability of additive manufacturing operations in the metal space. The applications were reviewed, revealed how crucial knowledge of design for additive manufacturing is in the supply chain for adopting organizations.

What we noticed was that the literature, the management literature put out a somewhat overestimated view of the capabilities of additive manufacturing. So, with the concept of design freedoms, where you are able to realize any design for your end application without any restrictions. But we found that the reality on ground is actually far from what the management literature puts out.

There are indeed some design limitations with additive manufacturing depending on what process you are using. So, for example, with selective laser melting I am depending on what the requirements of your end application are. There might be limitations as to the fit, the size of walls or the thinness or thickness of walls that you can realize with your selective laser melting process.

On the other hand, there are also limitations imposed by the capabilities of the post processes in your supply chain. So, a very good example is CNC machining. It is been around for many decades, but it is been used mainly in the traditional manufacturing supply chain to work on sort of standard shapes where there are standards established, industry standards to go about those methods.

But when it comes to additive manufacturing, you have a lot of complex monolithic designs, a lot of which are too complex for you know CNC machining to finish depending on the end application requirements. So, in essence, designers need to work with the practicalities of the CNC machining process for their finishing operation and the other examples, when it comes to inspection, you need to know the limitations of your inspection capability.

For example, x rays and there might be limitations as to the sort of parts and orientations that can be thoroughly inspected with those processes. So, those considerations need to be factored in at the design stage during product development to ensure that application production, applications are viable through the supply chain.

This makes it absolutely imperative for co-creation all the entities in the supply chain to participate in the design process to factor in the imputes of the various post process and to make sure that applications are viable. That is on the one hand. On the other hand, during build preparation of before build preparation, the knowledge of design for additive manufacturing is absolutely crucial in orienting parts in the build envelope.

This is a very important phase where manufacturers seek to eliminate as much post processing as they can regarding support structures. So, there are concepts such as self-supporting angles that manufacturers may want to take advantage of to eliminate post processing and reduce the burden in the supply chain and reduce costs.

A lot of manufacturers, have these explicit strategies in their toolbox to minimize post processing, so that they can reduce costs in their supply chain and lastly and it is on the preprocessing stage, manufacturers also seek to maximize the capacity of their

build envelope. This is very important because this is one of the dimensions that additive manufacturing is held on.

The ability to make a variety of parts in a build envelope. But what we also discovered was that there are limitations when it comes to industry requirements. So, for example, in the aerospace sector, if parts have been qualified with one part in the build during certification, that configuration is frozen or through the lifecycle of that part in production. It limits the scope for you to maximize and to you know be flexible with your production operations.

So, that was an interesting take home from a researcher practicality point of view.

**(Refer Slide Time: 09:32)**



Another very important aspect to consider is quality control. This is absolutely crucial because as our applications revealed, quality problems can actually crystallize in your part, which originated from the impure processes in the supply chain. So, for a good example is the fact that porosity can actually crystallize in your end-use apart from the porosity found in powders that you source from your suppliers.

This makes it absolutely crucial for organizations to invest in the right quality control infrastructure to ensure that they can carry out the necessary quality checks to ensure that their materials have the right quality before they go into the manufacturing process. In the same vein, when it comes to the machine, the manufacturers need to pay attention to maintenance of those machines.

So, when it comes to management of consumables such as filters, etc., the gases in the gas chamber for selective laser melting processes, even up until the environmental control conditions in the room way or additive manufacturing machines are these elements need to be taken into consideration as one of the respondents and put it to described metal additive manufacturing as operating in a very sensitive parameter space.

So, it is important to pay attention to each and every element. That also goes on to powder management. As you all may know, additive manufacturing is also esteemed for the ability to recycle raw materials, to recycle powders for reuse.

But what is also absolutely crucial to understand is that there are limitations that vary from industry to industry. For example, aerospace, their limitations and how much you can recycle and reuse your powder due to the oxygen content and associated quality properties. Lastly, the health and safety requirements of organizations absolutely crucial.

Organizations must invest in the right personal protective equipment for their operators, as you can see in the diagram in the form of masks and then you know, gloves because some of these powders are actually hazardous. They need the right investments to protect the employees. So, I mean, this presents a practical view of the ancillary investments that organizations need to invest in for the additive manufacturing operations.

**(Refer Slide Time: 12:57)**



The additive manufacturing capability is another important factor to consider during implementation. It was very interesting to understand you know, the nuanced landscape and how capabilities differ from process to process and how those capabilities in turn affect the quality of parts that come out of the build and in essence, the level of post processing depending on the requirements of your end application.

So, for example, selective laser melting has different capabilities compared to electron beam melting. Electron beam melting is regarded as a hot process and therefore, stress relieving of parts happens in situ. That is not the case with selective laser melting and a separate heat stress relieving heat treatment process has to be carried out after the build to ensure that parts have the right quality.

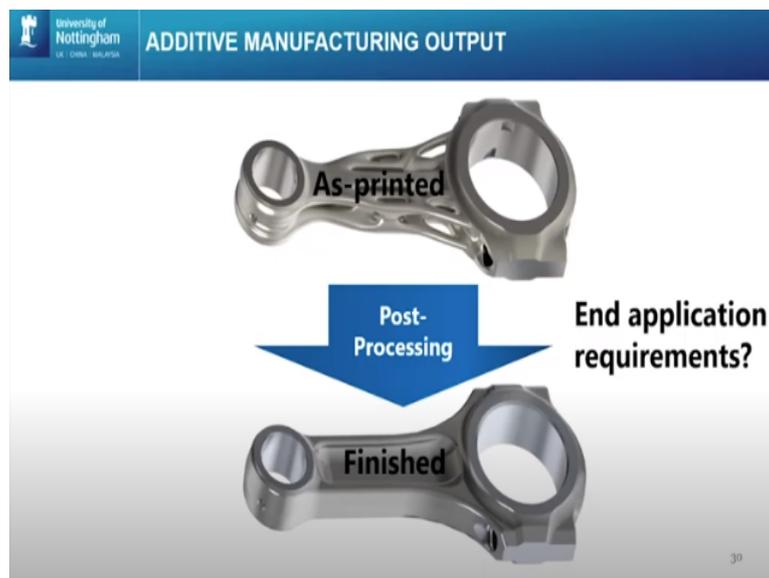
There is also a reduced scope to nest or to maximize a build envelope and selective laser melting because parts have to be welded to the build plate and there is an increased scope to do that, as seen from an electron beam melting from some of the applications that we studied. We also noticed that there are different quality requirements that guide process selection. So, for example, selective laser melting has different porosity levels as compared to electron beam melting.

The same can be, the same argument can be made for the surface finished qualities of the two different processes. These considerations are actually crucial for adopters and potential adopters to understand with respect to the requirements of their end

applications. Some manufacturers may choose to select you know SLM because it produces finer features and dependent on the requirements of their end application.

It is absolutely crucial to understand the relationship between the capabilities of this process and the corresponding post processing supply chain that goes along with it.

**(Refer Slide Time: 15:44)**



So just before I talk about post processing, we need to understand the additive manufacturing output, what comes out of the build envelope. Because it is a key to unlocking the configuration of the supply chains. So, a lot of manufacturers refer to it differently. Some people call it as printed, part that comes out of the build envelope. Some people call it the AM blank.

Whatever you know, is used to refer to what comes out of the build envelope, what we found was that most parts you know need to go through one form of post processing or the order to get to a finished state depending on the end application requirements. So, I am not sure what this component is, might be a caliper or something for an end application.

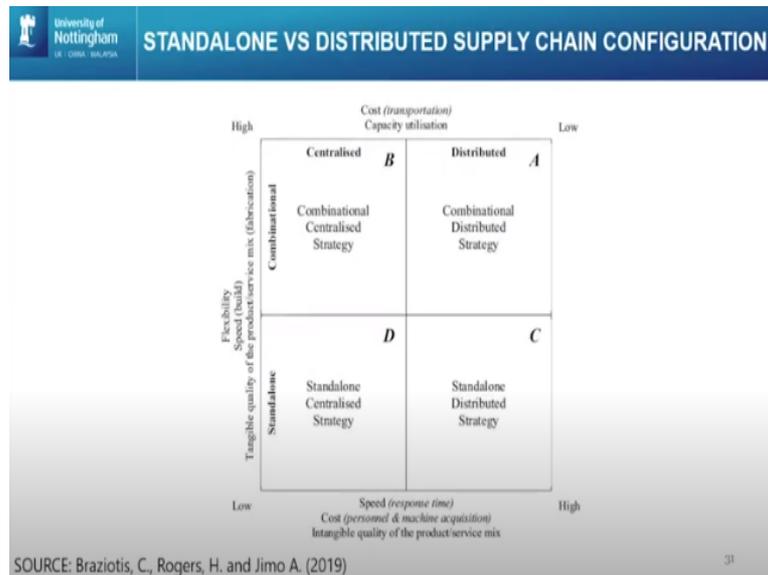
Whereas you can see, the diagram in the top section of the screen shows a part with supports mounted. These supports need to be removed and possibly parts need to be finished, machined for the end application requirements. If you look at the aerospace sector for example, they might be interested in fatigue requirements. Therefore, insist

that parts of finished machined, so that they are no crack initiations and crack propagations.

This is absolutely something that is important for adopters to understand because the management literature again puts out this vision of having finished parts from your build envelope. But the vast majority of applications that we studied actually showed that you need one form of post processing idea. I think the shortest application that we reviewed needed a vibration finish at the least for the part to go into the end application.

So, I guess this is also a question for the innovators to look at. Can they actually develop AM process capability to the level where parts are used just coming out from the build? Again, that question is not does not have a straight answer, because applications vary across different sectors and parts may not have so critical requirements and may need to may not need significant post processing.

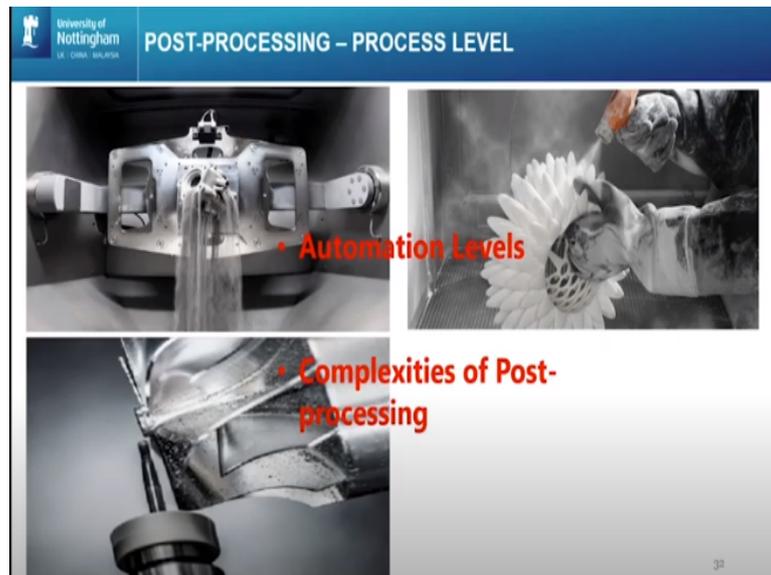
**(Refer Slide Time: 18:35)**



So again, before I talk about the post process, and I would like to revisit the concept of the standalone and the combination of configuration as was discussed in the first part of this presentation. So, as I mentioned earlier, this standalone process configuration talks about your 3D printer making parts for your end use applications. But I also mentioned, the vast majority of applications require one form of post processing or the other.

They require an interaction with a traditional manufacturing process which might be a CNC machining or it might be a heat treatment process. So, we find that the vast majority of configurations fall into quadrant B, where there is not dependence. They still that dependence on traditional manufacturing. There still be a dependence on the concepts of economies of scale which tend more to centralization.

**(Refer Slide Time: 19:56)**



As I mentioned earlier in my presentation, I talked about the polymer additive manufacturing applications enabling scope to distribute manufacturing capacity. But in the metal space, it is still that is still far from the case for the vast majority of applications that we looked at. So, at the level of the process for post processing, what we found to be interesting was the different levels of automation across cases.

Additive manufacturing is supposed to be an automated process, that is one of the attractive features. I am especially talking about manufacturing in developed economies, where labor costs are very high. So, we want to eliminate all the assembly processes and all the intermediate manufacturing steps and create part in an automated build envelope.

But the problem is that when you have post processing, there is some form of manual intervention, which requires labor impute. So that might be during your powder removal or your support removal. In the most rudimentary of cases, we found operators using pliers and screwdrivers to remove supports from parts. So that in essence, reduces the level of automation and also increases costs in the supply chain.

This is why manufacturers place a lot of emphasis on elimination of support structures during the design phase and also when you think about powder removal is also very crucial. In the diagram on the top left-hand side of the screen, you can see an automated powder removal machine that orients parts in different ways to remove the powder. This is all well and good when you have simple designs.

But when you have complicated designs that have hollows and you know very small intertwined channels and might be difficult for these processes to evacuate the powder. So, you need some manual intervention and that you know, increases cost and the supply chain reduces the level of automation. That is on the post processing level. It was also important to observe that you know, with additive manufacturing we can make all these complex designs.

But the problem is that we create challenges in post processing, because yes you can make a, you know organic design that you know can reduce the weight of a component. But the question is how are you going to finish that component if you know it is required for the end application. So very interesting to understand this tradeoff in the supply chain.

**(Refer Slide Time: 23:24)**

University of Nottingham  
UK CHINA INDIANIA

### POST-PROCESSING – SUPPLY CHAIN LEVEL

- Number of batch and Non-batch processes
- Degree of vertical integration
- What level of co-ordination is required?
- Capabilities of local supply base



On the supply chain level, what was interesting to observe was varying dimensions of characteristics to understand you know the configuration. The first interesting characteristics had to do with the length of the supply chain and this has to do also

with the number of batch and non-batch processes that you have in your supply chain. As I mentioned earlier your post process may be of a batch or a non-batch nature.

The batch processes were particularly interesting, because they depend on economies of scale processes such as stress relieving, heat treatments. There is scope for you to maximize your the oven and cycle time and reduce the you know costs of your parts. In the aerospace sector a very highly sought after processes the hot isostatic pressing and this is a very expensive process.

Very capital intensive, specialized and usually owned by specialist suppliers in the supply chain. What was interesting to understand about this process was that it requires volumes of parts to run cycles so that attendant overhead costs can be reduced. But with a low volume additive manufacturing supply chain, there is reduced scope to do that, especially if you want your parts quickly.

So, what we found was that you know, this process was subcontracted in most applications. But suppliers face delays in most cases. Because the specialized suppliers are looking to utilize their capacity and so are looking to pull volumes from different customers and this creates delays in the supply chain, which defeats the whole essence of rapidness or responsiveness when it comes to additive manufacturing.

So, we saw that some big aerospace manufacturers were actually looking to vertically integrate this process. But that is a tall and an impossible order for SMEs who do not have the capital deep pockets to buy these processes. The same philosophy can be applied to other processes such as inspection where you have CT scanning. Very expensive processes. So, it is important to understand the nature of this processes along the supply chain.

Another dimension was also the degree of vertical integration. So, what we found was that the vast majority of cases, manufacturers would vertically integrate the core post processes. That might be powder removal, stress relief treatment, or substrate removal for SLM processes.

But when you move further down the chain to some specialized processes, as I mentioned earlier, heating in aerospace, CT scans, it becomes very expensive. So, manufacturers need to understand how to balance the requirements of the applications with the available capabilities in house and also in the external supply chain.

As I mentioned earlier, the level of coordination, the requirements increase as the more you outsource processes to your supply chain. So, chances are that you would encounter delays, depending on the relationships that you have with your partners in your supply chain. A lot of them are used to, large volumes. They are not used to dealing with one of parts for the additive manufacturing supply chain.

This also indicated the incompatibility of business models in the supply chain. We need more tailored business models in amongst service providers to be able to accommodate the one of nature of additive manufacturing that agile one of you know, niche space of additive manufacturing, that needs to be enabling business models.

Lastly, something that, you know lipped out as very important was also the varying maturity, maturity levels of supply chains across different economies. So, what we found looking at companies in the US and the UK and Germany, the supply base for post processing is more mature. Understandably so because a lot of this countries are leading in additive manufacturing.

But when it comes to developing economies, what we found in India was that there was a lack of some of these specialized processes. Manufacturers had to go all the way to Germany to source some of these processes and that indeed creates bottlenecks and delays and also increased cost because of the logistic requirements.

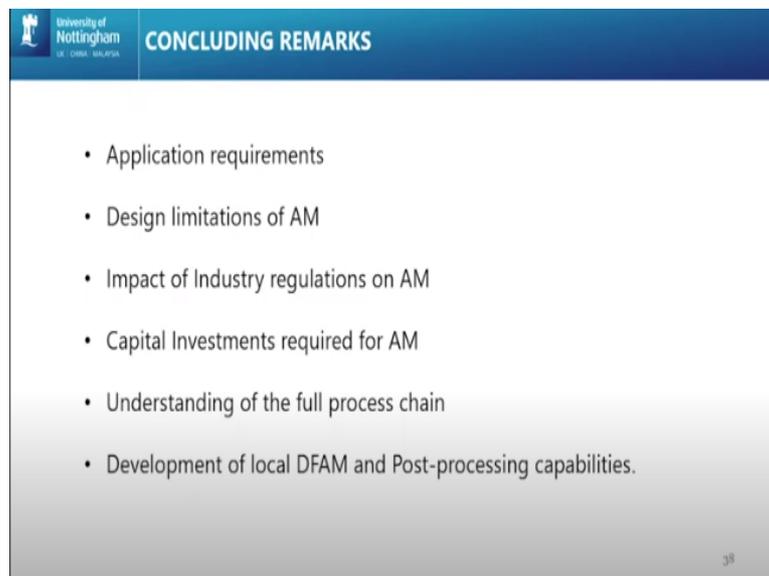
So, this is something for adopters and potential adopters of additive manufacturing to consider during implementation, what is the state of my local supply base because if you think about it, additive manufacturing, we talk about the capabilities to enable localization. But it sounds counterproductive if you have to go overseas to post process one part. It does not really sound like a viable application.

So, there is a need for post processing capabilities to be developed in the local supply base to make application viable. We talk about majority of supply basis in Europe but with Brexit coming in the UK it also threatens you know the availability of some of these processes in the supply chain. Some manufacturers in the UK for example, still resort to extend outsources.

But the red tape at the border might create delays and viability of applications might be threatened. Think about rapid spares applications, where downtime costs of aircrafts going up by the second and parts need to be delivered quickly. Red tape and bottlenecks at the borders will not be welcome for those kinds of applications. Also, for applications such as finished machining, as I said earlier, it is still a very immature space.

A lot of suppliers do not have the capabilities to finish complex geometries for instance. These capabilities need to be developed from an institutional point of view. So, looking at educational curriculums and how that can be factored in apprenticeship schemes and undergraduate and post graduate programs, so that the necessary talent and capabilities can find their way into the supply chain.

**(Refer Slide Time: 31:45)**



University of Nottingham  
UK CHINA MALAYSIA

## CONCLUDING REMARKS

- Application requirements
- Design limitations of AM
- Impact of Industry regulations on AM
- Capital Investments required for AM
- Understanding of the full process chain
- Development of local DFAM and Post-processing capabilities.

38

So, these are some of the findings or some of the implementation factors that lead to ouster in our research over the past couple of years looking at the metal additive manufacturing supply chain. So, in summary, we see that the additive manufacturing

management literature puts out an over estimated view of vision of the capabilities of metal additive manufacturing.

It is absolutely crucial for organizations to understand the limitations. So, limitations when it comes to design for additive manufacturing, limitations when it comes to post processing, and also the capabilities of their local supply base as was discussed earlier. They need to understand the tradeoffs that need to be made with respect to the requirements of their end applications.

We also need to understand the impact of industry regulations on additive manufacturing, the performance of your supply chain. The example I like to cite is the aspect of maximizing build envelopes. So, the management literature puts forward this view of flexibility where you can on the fly in a very agile way maximize the capacity of your additive manufacturing operation.

But I mean, when you think about aerospace and the requirements for traceability, the scope to do that is a lot limited, that there is more leeway to do that in less regulated sectors such as a motor sport. But again, there are technical limitations with regards to, using your build and you know, having successful builds.

So, all this tradeoffs or requirements and limitations need to be adequately understood by manufacturers in implementing additive manufacturing in their supply chains. Also, we need to move away from this you know, view of having 3D printers. We need to have a holistic view understanding the ancillary infrastructure that goes with additive manufacturing.

So, whether that has to do with quality control the, environmental conditions and powder management, all the ancillary infrastructure that goes with additive manufacturing, we need to understand the full process chain to carry out proper implementation across different sectors and different organization and lastly, I would like to reemphasize the development of local capabilities in additive manufacturing.

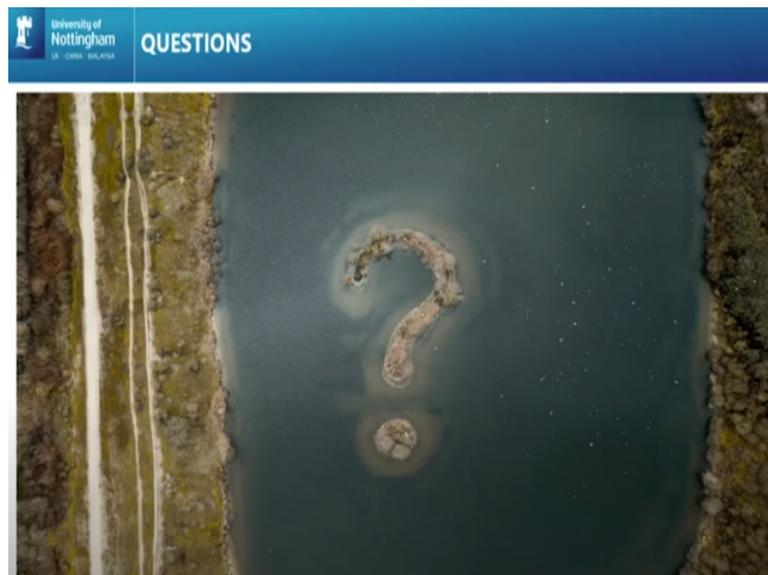
So, whether that has to do with design for additive manufacturing, there is a lot of work that needs to be done even in developed economies. Because as we know a lot

of in the design for additive manufacturing space, there is a lot of artificial intelligence involved and traditional designers are still restricted with old cultures of design floor manufacturing.

Not saying that they are not limitations in additive manufacturing, but it is just a different space that needs to be well understood and also the post processing capabilities. We also understand that there are improvements along that trajectory. Manufacturers are looking at optimizing the processes more for additive manufacturing.

So, all these considerations are important to understand if we are going to realize distributed manufacturing, which seems to be a lot further along into the future than it might be currently. So, these are absolutely crucial to understand for different adopters and potential adopters alike.

**(Refer Slide Time: 36:28)**



This brings me to the end of my presentation. As I mentioned earlier, if there are any inquiries or your questions you want to ask, you can send me an email that I would share at the course or by the end of this presentation in the next slide. Thank you very much once again for listening to this presentation, and goodbye.