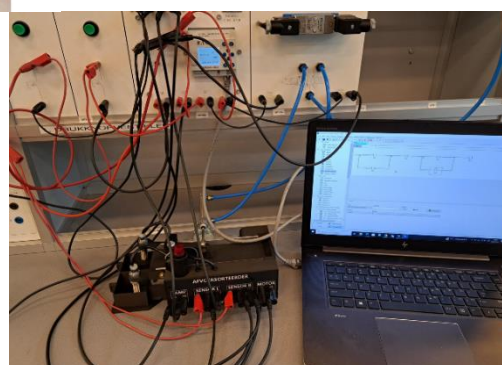
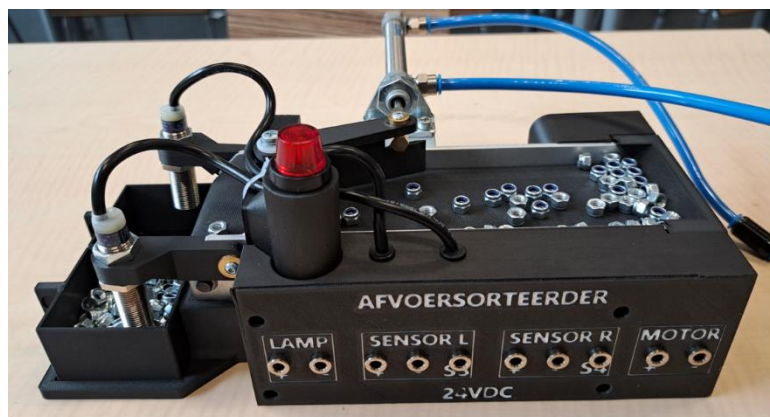


# ONTWERPDOSSIER AFVOERSORTEERDER



[Filmpje Afvoersorteerder](#)

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## Inleiding

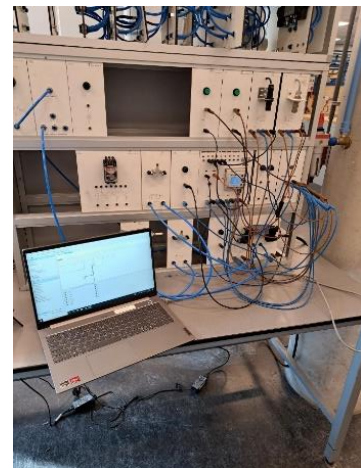
Ter afronding van mijn opleiding “Professionaliseringstraject PIE” moet een geïntegreerd onderwijsmiddel worden ontwikkeld en vervaardigd. **Dit dossier is aangepast n.a.v. van Criterium Gericht Interview (CGI) in juni 2023. De afwijzing hield voornamelijk in dat er sprake was reverse engineering van een CSPE-opdracht die niet expliciet in het dossier werd genoemd. In hoofdstuk 5 heb ik hierop gereflecteerd m.b.v. het model van Korthagen.**

Als onderwijsmiddel heb ik, in overleg met mijn collega’s en begeleidende docenten van Windesheim gekozen om een afvoersortermachine te ontwikkelen en te maken. Het betreft een opdracht die reeds in ons PTA is opgenomen onder in de verplichte module “Besturen en Automatiseren”. Voor deze opdracht wordt rechtstreeks het blauwe onderdeel D van CSPE 2019 gebruikt.

[https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

De PTA-opdracht draagt nog thans de “Afvalsorteerder”. Wel willen we meer de nadruk leggen dat het apparaat gebruikt wordt om te waarborgen dat productieprocessen gecontinueerd worden in fabrieken, van bijvoorbeeld afvoer en collecteren van M4-moertjes. De naamgeving in ons PTA zal op termijn dan ook gewijzigd worden van “Afvalsorteerder” in “Afvoersorteerder”.

De aanleiding voor de keuze is dat leerlingen (KB-niveau) een schakelopdracht met een besturingsprogramma maken op het schakelbord en laptop, maar vaak moeilijk een voorstelling kunnen maken hoe een installatie er in het echt zou kunnen uitzien, laat staan de voordelen te bedenken bij automatisering. De huidige PTA-opdracht is het uitwerken van de genoemde opdracht. Bijgaand plaatje laat zien dat het geheel niet bepaald tot de verbeelding spreekt. Hierbij moet niet uit het oog verloren worden dat het juist aansluiten van stuurventielen, sensoren e.d. en programma-invoer een vast deel moet blijven uitmaken van de PTA-opdracht. M.a.w. niet een volautomatisch apparaat, met, bewijze van spreken, alleen aan/uitknop.



*Figuur 1 Hoe de huidige uitvoering eruit ziet*

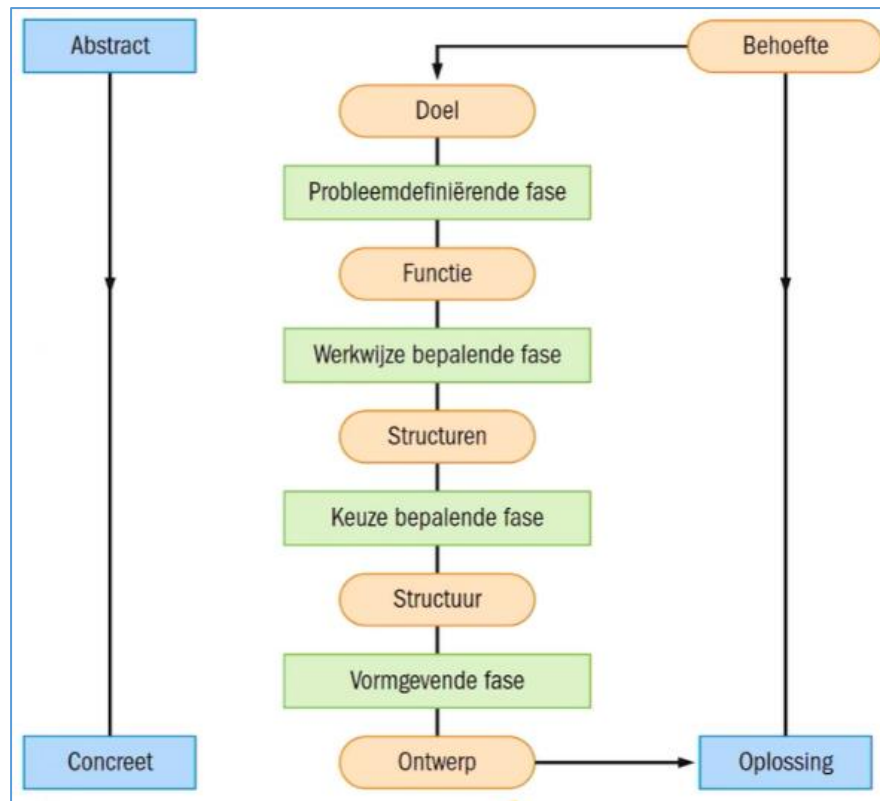
Daartoe ontsproot het idee een apparaat te ontwikkelen, waarmee de leerling daadwerkelijk ziet waarvoor zo’n de afvoersorteerder dient, dan alleen wat knopjes, sensoren, lampjes en een heen en weergaande luchtcilinder.

Bij het vervaardigen van de afvoersorteerder zijn twee van de drie PIE-vakbekwaamheden bevatten.

De afvoersorteerder zal ingezet worden ter afronding van een summatieve PTA-opdracht. Naast het fysieke product zal een duidelijk opdrachtomschrijving voor de leerlingen moeten komen, waarmee ze zelfstandig aan de slag gaan.

Ik heb de stappen uit het boek Basisboek Ontwerpen van Wim Zeiler gevolgd om zo mijn ontwerpdocument te maken. (Zeiler, 2014). Daarbij is het proces ingedeeld in de volgende fases: A - probleem definiërende fase. B - werkwijze bepalende fase. C - keuzebepalende fase. D - vormgevende fase. Hier is het eindproduct in werking te zien: [Filmpje Afvoersorteerder](#)

Vooraf gaand is een Plan Van Aanpak (PVA) gemaakt, die in bijlage H is opgenomen.



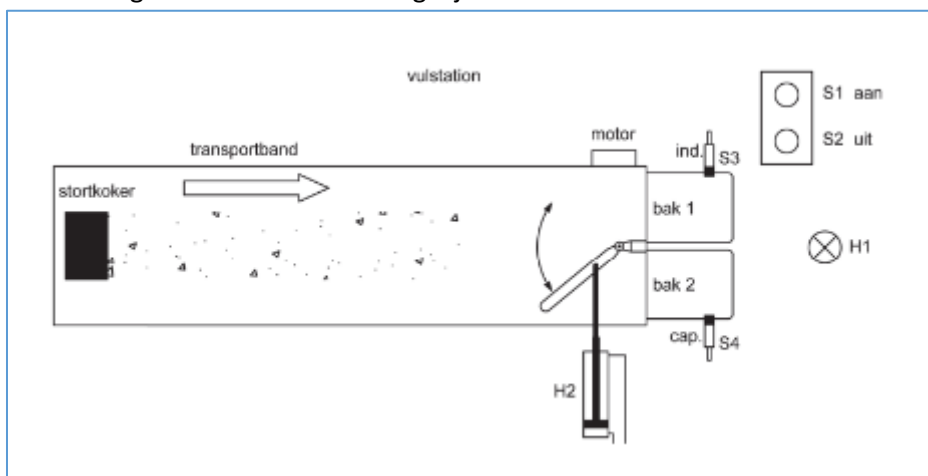
Figuur 2: Ontwerpfasering volgens Zeiler (Zeiler, 2014)

## 1. Probleem definiërende fase

### 1.1. Probleemstelling m.b.t. de huidige PTA-opdracht

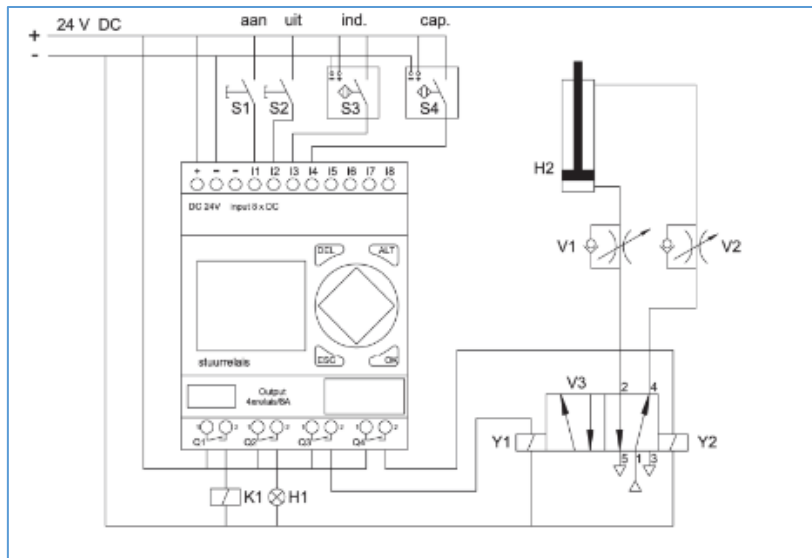
De werkelijke (hetzij onbewuste) opdrachtgevers zijn onze leerlingen. Ze geven dikwijls aan geen beeld te hebben waarom en hoe besturingstechniek, in het bedrijfsleven, wordt toegepast. Na een aantal formatieve opdrachten, zoals elektropneumatiek, programmeren en aansluiten van de EasyRelais, moeten de leerlingen de summatieve PTA-opdracht is de zogenaamde “Afvalsorteerder” voltooien. Dit is een opdracht waarvoor rechtstreeks het blauwe onderdeel D van het CSPE 2019 is gebruikt. [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

Ondanks afbeelding in figuur 3 en de opdrachtomschrijving is het voor de leerlingen lastig zich een voorstelling te maken hoe een dergelijke installatie er in het echt zou kunnen uitzien en werken.

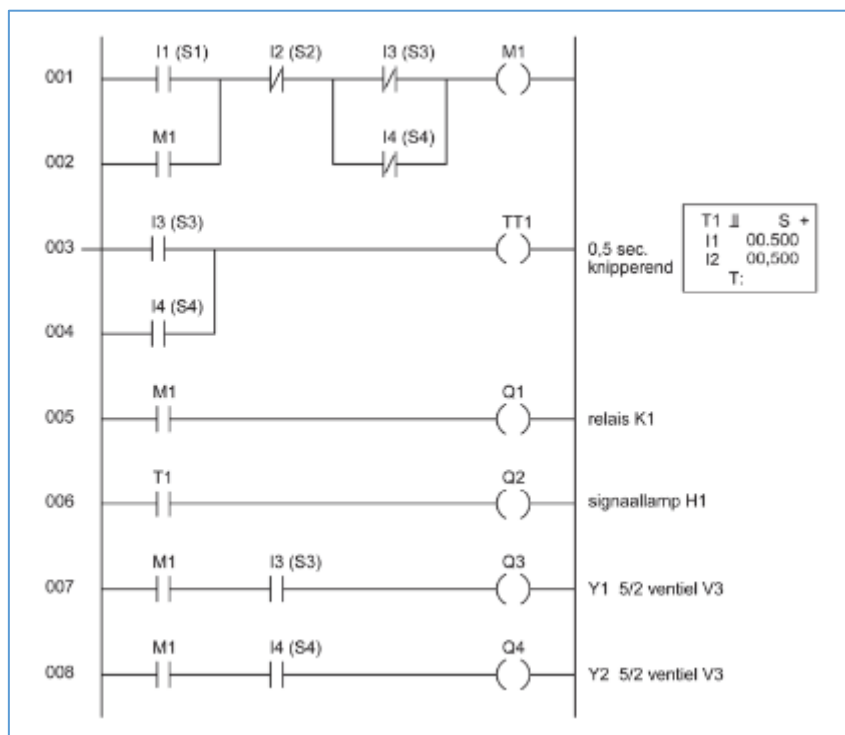


Figuur 3 De afvalsorteerder (College voor Toetsen en Examens, 2019) (bron CSPE 2019, onderdeel D Blauw)

Het programmeren wordt vaak als lastig ervaren en de toepassing besturing en automatiseren, in het bedrijfsleven, zijn voor hen veelal abstract. Met een apparaat, die ook daadwerkelijk datgene doet, wat in de opdracht staat omschreven, zal het nut duidelijk worden en de materie beter beklijven.

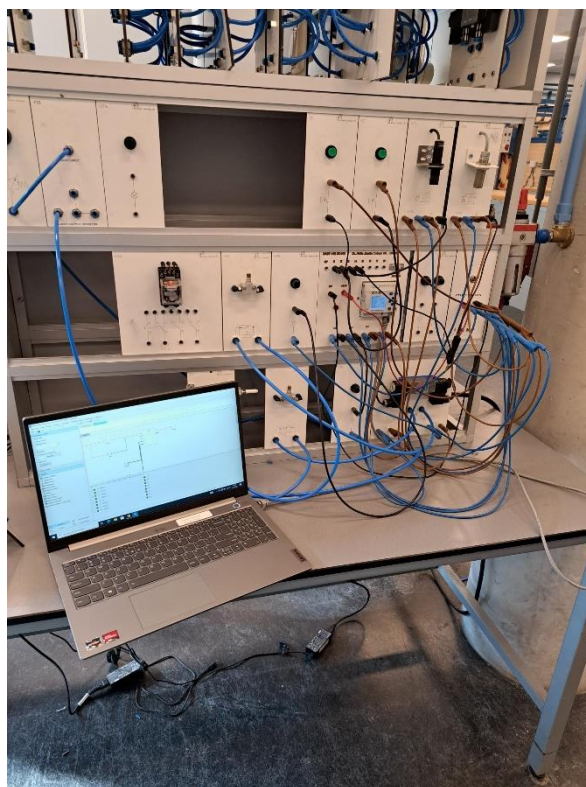


Figuur 4: Elektro pneumatisch schema voor de afvalsorteerder (College voor Toetsen en Examens, 2019) ([bron CSPE 2019, onderdeel D Blauw](#))



Figuur 5: Ladderdiagram voor de afvalsorteerder (College voor Toetsen en Examens, 2019) ([bron CSPE 2019, onderdeel D Blauw](#))





Figuur 6: Zoals de opdracht nu in praktijk wordt uitgevoerd

Hierbij waren, voor mij, de 7 Hulpvragen (6 W's) van (Verhoeven, 2018) een hulpvolle methode:

<b>Wie</b>	Leerling.
<b>Wat</b>	Door abstractie onduidelijkheid over het nut bij de leerling.
<b>Waar</b>	Op de werkplekken/experimenteerborden waar de opdrachten worden uitgevoerd.
<b>Wanneer</b>	Bij het uitvoeren van de summatieve opdracht "Afvalsorteerder".
<b>Waarom</b>	Een aangesloten en geprogrammeerde EasyRelais met alleen actuatoren als schakelrelais, een signaal lamp en dubbelwerkende persluchtcilinder geeft geen duidelijk genoeg beeld over waar het voor dient. Ook de toepassing van de ingangssignalen m.b.v. capacitieve en/of inductieve sensoren spreken niet tot de verbeelding. Dus is een werkend apparaat nodig waarmee gedemonstreerd wordt, wat er na gebeurt als het eerst bakje volloopt, enz. ....
<b>Waardoor</b>	Leerlingen hebben (nog) geen excursie gehad bij een procesfabriek waar automatisering wordt toegepast. Naast technisch ook geen (volledig) beeld van economisch voordeel (humane arbeid versus automatisering/robotisering).

Naar (Verhoeven, 2018)

## 1.2. Doelstelling

Het ontwikkelen en maken van een leermiddel (afvoersorteerder) waarmee leerlingen bewust worden gemaakt van het nut en doel van besturingstechniek. Met dit middel leert de leerling het juist aansluiten en programmeren van de besturing. Ook worden de leerlingen in aanraking gebracht van professioneel 3D-printen, met versterkte composieten.

Zoals al eerder wordt de naam van huidige PTA-opdracht “**Afvalsorteerder**” gewijzigd in “**Afvoersorteerder**”. **Hiermee wordt de link gelegd dat een machine moertjes fabriceert, waarbij de eis is dat het proces continue moet doorgaan. Alleen als de operator verzaakt bij legen, zal het proces stoppen.**

De opdracht is bestemd voor PIE KB-leerlingen en gaat van de syllabus van de verplichte module “Besturen en Automatiseren” de volgende delen afdekken en kunnen als vaste eis worden beschouwd:

- Van deeltaak, P/PIE/3.1: 1, 2, 3, 4, 6, 7 en 8.
- Van deeltaak, P/PIE/3.3: 1 t/m 5.

Het programma van eisen zijn in navolgende paragraaf uitgezet. Belangrijkste (en dus vaste) eis is dat de te maken installatie direct ingezet kan worden voor het uitvoeren van onderdeel D, van CSPE 2019, die opgenomen is in ons PTA (Programma van Toetsing en Afsluiting) van de verplichte module Besturen en Automatiseren. [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

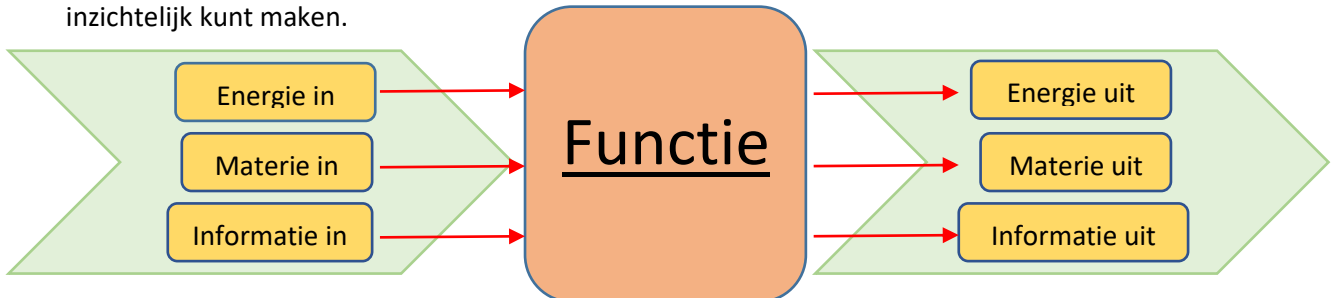
### 1.3. Programma van eisen

Functioneel	Fabricage	Programma van eisen	Vaste eis	Variabele eis	Wens	N.v.t.
X		De installatie moet geschikt zijn voor het uitvoeren van onderdeel D van CSPE 2019. Deze is opgenomen in het PTA van module Besturen en Automatiseren.	X			
	X	Idem.		X		
		<ul style="list-style-type: none"> <li>De opdracht moet de delen P/PIE/3.1 van Besturen en Automatiseren afdekken, op KB-niveau. Met de productieafvoerder moeten de volgende onderwijscomponenten uitgevoerd kunnen worden:</li> </ul>				
X		1. Een pneumatische schakeling opbouwen.	X			
X		2. Een programmeerbare EasyRelais aansluiten en een programma invoeren.	X			
X		3. Sensoren en actuatoren kiezen en aansluiten.	X			
X		4. Een regelsysteem opbouwen, aansluiten en testen.	X			
		5. Een domotica-installatie opbouwen, aansluiten en testen.				X
X		6. Storingen en fouten zoeken en verhelpen in de opgebouwde schakeling.		X		
		7. Metingen uitvoeren aan een besturingsinstallatie.				X
		8. een verslag maken en de resultaten presenteren			X	
		<ul style="list-style-type: none"> <li>De opdracht moet de delen P/PIE/3.3 van Besturen en Automatiseren afdekken, op KB-niveau. Met de productieafvoerder moeten de volgende onderwijscomponenten uitgevoerd kunnen worden:</li> </ul>				
X		1. Besturingscomponenten plaatsen aan de hand van een opstellingstekening.		X		
X		2. De besturingscomponenten bedraden en aansluiten aan de hand van een bedradingstekening.	X			
X	X	3. Een programma invoeren in een programmeerbaar relais.	X			
X		4. De automatische besturing testen.		X		
		5. De automatische besturing demonstreren en presenteren.	X			
X		De opdracht moet in 3 lesuren van 45 minuten gerealiseerd kunnen worden.	X			
X		100% van de productiedelen (moertjes) moeten tijdens transport aankomen.		X		
X		Afvoerproces mag niet stoppen moet continue doorgaan. (Door bijvoorbeeld productieafvoer automatisch in 2 stromen te kunnen leiden).	X			
X		Operator moet tijdig gewaarschuwd worden als het proces dreigt te stoppen.	X			
X		Als de operator verzaakt om tijdig in te grijpen, moet het proces alsnog stoppen.	X			
	X	Snelheid afvoertransport moet 50mm/s zijn.		X		
X		Veiligheid: afscherming van aandrijving.	X			
	X	Afmetingen afvoersorteerder: L x B x H = 300 x 100 x 100.		X		
	X	Gewicht ≤ 5kg.		X		
	X	Te maken met cataloguskoopdelen, 3D-printer, plaatdelen 2mm en inkoopdelen Brink Techniek BV.		X		
	X	De maakkosten mogen niet hoger dan €500,-.		X		
	X	De afvoersorteerder moet gemaakt kunnen worden in 3 maanden.		X		
	X	Bij een val van 1,5m geen ontzetschade aan de ophanging.		X		
X		Weinig onderhoud.		X		
	X	Defecte geraakte onderdelen moeten binnen 24 uren te vervangen zijn.		X		
X		Werking betrouwbaar.		X		
	X	Complexiteit onderdelen laag.		X		
	X	Zo weinig mogelijk onderdelen.		X		

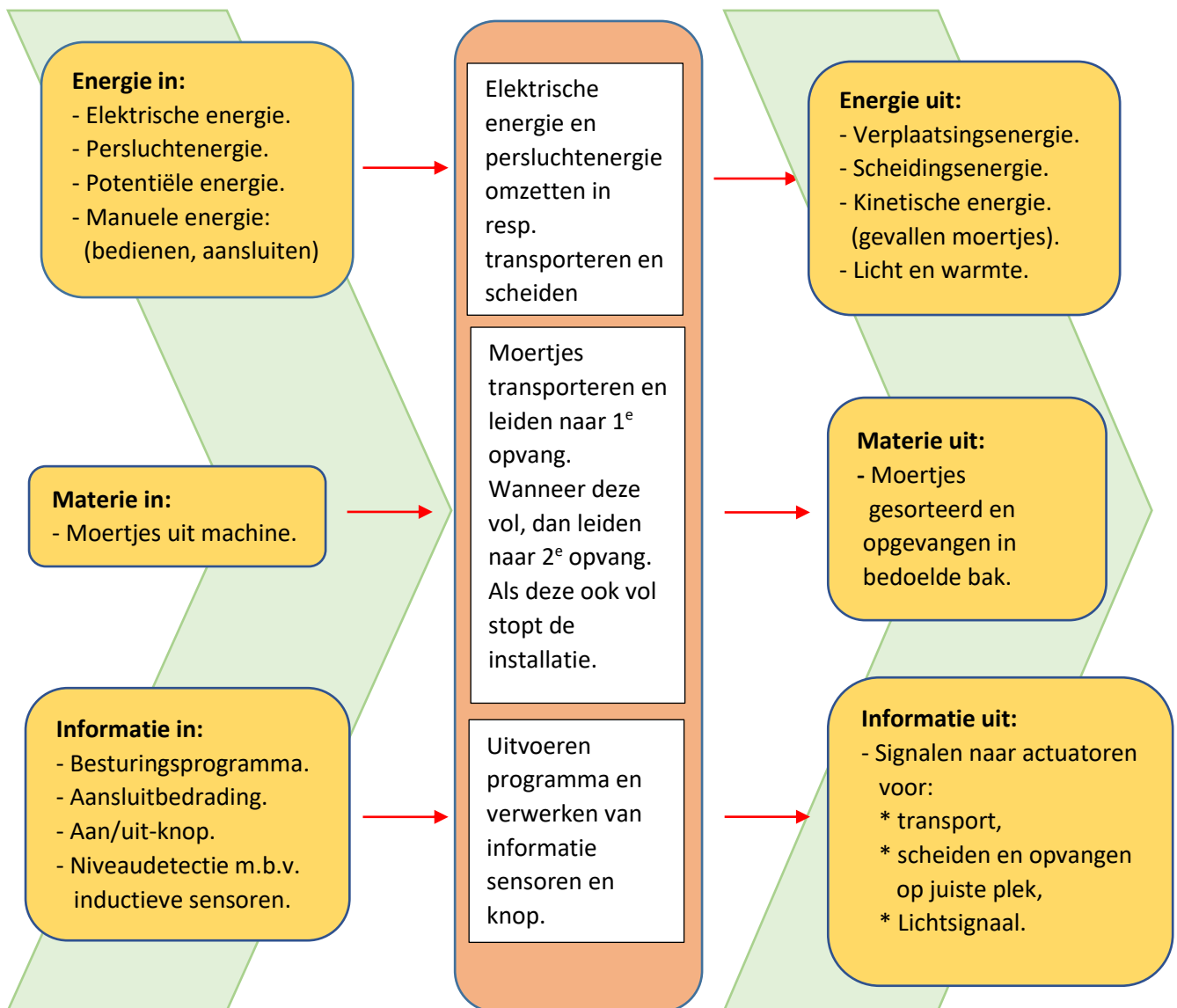
Naar (Zeiler, 2014)

## 1.4. MEI-diagram

In bijgaande MEI-diagram zijn de energie-omzettingen in kaart gebracht, waarmee helderheid gekregen wordt over de noodzakelijke functies. Hiervoor zijn figuren 3 gebruikt als leidraad (CSPE 2019, onderdeel D) [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf). Laten we wel wezen; het is mosterd na de maaltijd, maar het is wel interessant om te zien hoe zo'n diagram eruitziet in de gegeven situatie. M.a.w. hoe je de stromen inzichtelijk kunt maken.



Figuur 7: MEI-diagram algemeen (Zeiler, 2014)



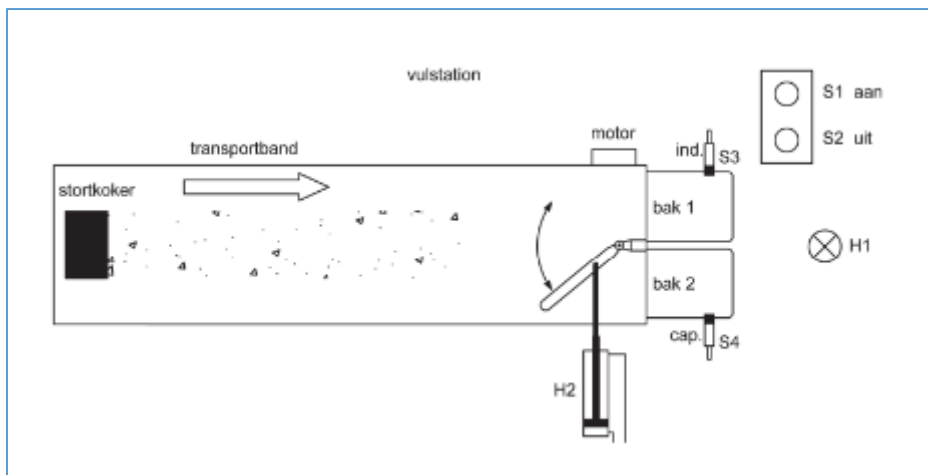
Figuur 8: Specifiek MEI-diagram naar (Zeiler, 2014)

## 2. Werkwijze bepalende fase

















De functies volgen uit de opdracht [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf) Nu kan er een morfologisch overzicht worden gemaakt. Hierbij heb ik 3 werkwijzen uitgezet.

### 2.1. Morfologische kaart

Omdat CSPE, onderdeel D, van 2019 wordt gebruikt, heb ik er niet voor gekozen om een geheel ander principe te gaan ontwikkelen, dan figuren 3, 4 en 5. Bijvoorbeeld: Het geleiden van schroefjes op de transportband naar de juiste bak zou namelijk ook op een andere wijze gedaan kunnen gaan, dan met een schuif die pneumatisch is aangedreven (bijvoorbeeld een kantelsysteem). Derhalve is dit (en andere principes) dan ook niet in de morfologische kaart opgenomen. M.a.w. een en ander is al reeds vastgelegd. Schematisch zal de afvoersorteerder er komen uit te zien als figuur 9. Er zullen zijframes nodig zijn waarin de motor, transportband, overbrenging en productscheiding zijn opgehangen.



Figuur 9 De afvalsorteerder (College voor Toetsen en Examens, 2019) (bron CSPE 2019, onderdeel D)

	Flexibele Transportband	Kettingband	
Transporteren moertjes			
Materiaal zijframes	Aluminium plaat	Verzinkte plaat	Kunststof 3D geprint
Materiaal omkasting	Aluminium plaat	Verzinkte plaat	Kunststof 3D geprint
Materiaal scheidingsschuif en opvangbakjes	Aluminium plaat	Verzinkte plaat	Kunststof 3D geprint
Materiaal transportrollen	Ø Messing	Ø automatenstaal	Kunststof 3D geprint met stalen asje
Signaallamp	Vast aan installatie	Los van installatie	
Instellen hoogte niveaudetectie S3 en S4	Statiefklem	Schroefbeweging	Scharnierend
			
Overbrenging	Tandwielen	Ketting	Aandrijfriem
			
Aandrijving	Brandstofmotor	Elektromotor	Luchtmotor
			
Programmeren Easyrelais	Directe handmatige invoer.	M.b.v. programma Easysoft	
			
Aansluiten bedrading sensoren, motor en signaallamp.	Krokodillebekjes op lipjes omkasting	Stekerbusjes in omkasting	
Keuzes die vastliggen n.a.v. CSPE-opdracht:			
1			
2			
3			



### 3. Keuze bepalende fase

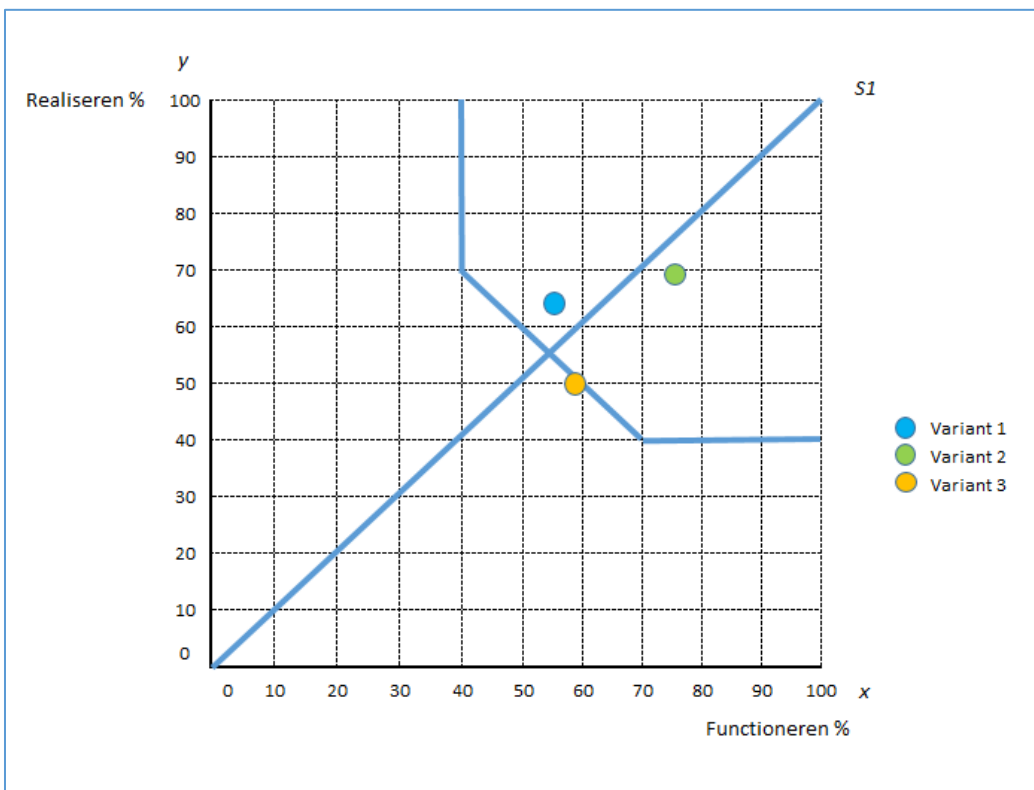
In deze fase wordt de keuze bepaald om door middel van het punten per werkwijze/uitvoering. Links staan de gebruikerseisen en rechts fabricage-eisen uiteengezet, wat als input in het S-diagram (Kesselring) zal dienen. Dit teneinde een verantwoorde en goede keuze te kunnen maken.

Gebruikerseisen	1	2	3	Ideaal	Fabricage-eisen	1	2	3	Ideaal
Makkelijk te handelen voor de leerling qua gewicht en afmetingen	2	3	2	4	Stijheid constructie m.b.t. buiging, wringing etc.	3	3	2	4
Opbouw en bedieningsgemak	1	3	2	4					
Syllabus: Geschikt voor opbouwen, aansluiten en testen	2	3	3	4	Defecte onderdelen kunnen binnen 24 uur gereproduceerd worden t.b.v. vervanging	1	3	1	4
Syllabus: Geschikt voor oefenen met storing en fouten zoeken	2	3	3	4	Fabricagekosten	3	2	2	4
Betrouwbare werking	3	3	1	4	Eenvoudige constructie	2	3	1	4
Veilig in gebruik	2	3	3	4	Eenvoudige montage	3	3	2	4
Weinig onderhoud	3	3	2	4	Toepassing inkoop/catalogusmaterialen	3	3	3	4
Werking moet tot de verbeelding spreken	3	3	3	4	Lage complexiteit onderdelen	3	2	3	4
Totaal X	18	24	19	32	Totaal Y	18	19	14	28
	56%	75%	59%	100%		64%	68%	50%	100%

Figuur 10: Beoordelingscriteria functioneren/gebruiken en realiseren/fabriceren

Bij het uitzetten van de drie werkwijzen blijkt variant 2 favoriet, met 75% gebruikerseisen en 68% fabricage-eisen. De S-lijn (S-1) is de 100% lijn en te zien is dat variant het dichtste bij deze ideale lijn zit.

Bovendien is te zien dat variant 3 buiten de grenswaarden (min. 40% per as en min 55% gecombineerd) valt en variant 1 op het randje zit.



Figuur 11: Kesselringmethode S-diagram

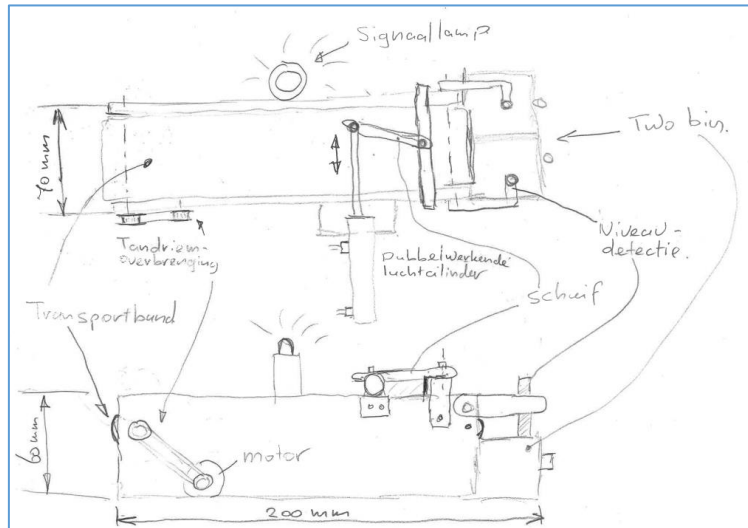
De methodieken hebben ertoe geleid dat de keus valt op variant 2 en dat ik kan starten met de realisatiefase.

## 4. Realisatiefase

Na de keuze gemaakt te hebben voor variant 2 is het tijd geworden om duidelijk te krijgen hoe het e.e.a. gerealiseerd moet worden.

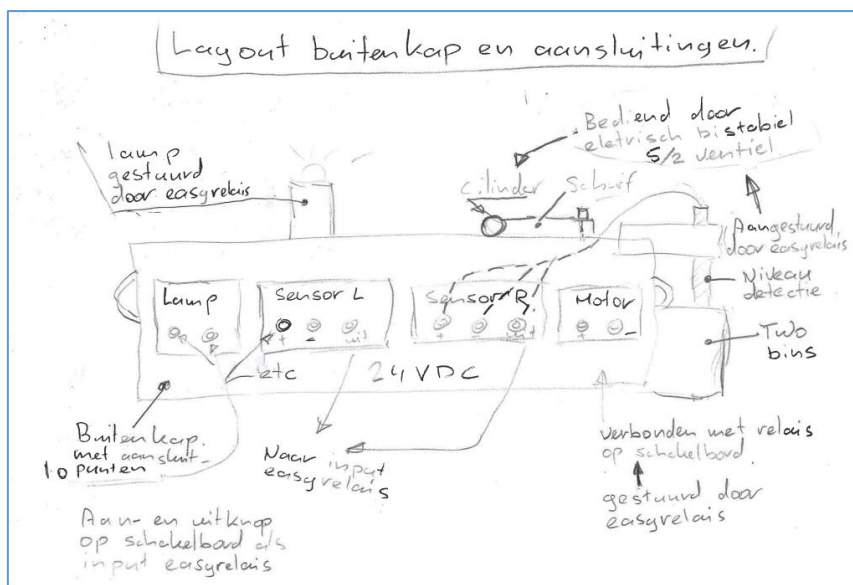
### 4.1. Schetsen

Uiteraard dient figuur 3, op bladzijde 7, hier als basis. De schetsen die hierop gemaakt zijn, dienen als input voor de CAD-tekeningen en inzicht te krijgen wat getekend en/of besteld moet worden.



Figuur 12: Schets boven- en zijaanzicht

In het programma van eisen hebben is duidelijk naar voren gekomen dat de afvoersorteerder geen kant- en klaar product moet worden, met, bij wijze van spreken, alleen een aan- uit knop. M.a.w. het correct aansluiten van de dubbelwerkende cilinder, het 5/2 bi-stabiel ventiel, aansluiten van sensoren, aansluiten van de signaallamp en het programmeren van de EasyRelais moet deel uitmaken van de opdracht. Aan de zijkant (o.i.d.) zal daarom een aansluitpaneel gerealiseerd moeten worden. Daartoe kwam de volgende schets tot stand.



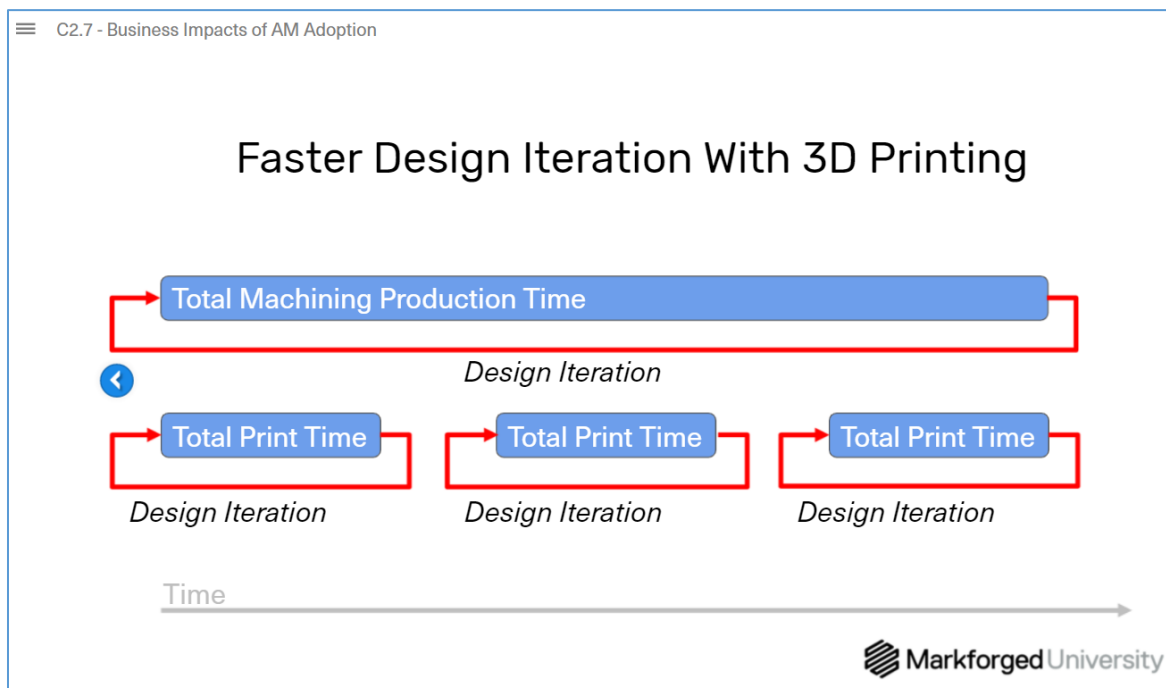
Figuur 13: Lay-out van de buitenkap en aansluitingen

## 4.2. Getekende 3D-modellen geprint

In de gekozen oplossing (variant 2) is opgenomen en gesteld dat defect geraakte onderdelen binnen 24h vervangen moeten kunnen worden (printer een nachtje laten draaien). Op onze deelschool is dit mogelijk, omdat we beschikken over 2 professionele printers waarmee onderdelen geprint kunnen worden, met treksterktes vergelijkbaar (of zelfs meer dan) van aluminium. Het betreft twee 3D-printers: "Onyx One" en de "Mark Two", beide van het merk Markforged.

De Onyx One kan alleen het basis-filament Onyx verwerken en wordt **Fused Filament Fabrication (FFF)**. De Mark Two kan daarentegen ook versterkte vezels worden toevoegen en wordt **Continuous Filament Fabrication (CFF)** genoemd. In de navolgende paragrafen 2.4.1 en 2.4.2 worden deze principes verder behandeld.

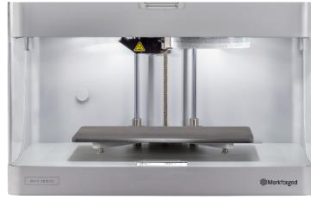
Bijkomend voordeel is dat, bij het ontwerpproces, snel beschikt kan worden over een aangepast product (iteratie): Sneller een definitief product, voor lagere kosten. Dit in vergelijking met bijvoorbeeld CNC-verspanen uit aluminium. Notie: Bij goede toepassing van versterkt materiaal, zijn bij 3D-printen zelfs hogere treksterktes mogelijk. Bijgaande figuur 14 komt uit de onlineopleiding "Markforged University Composites Training" die ik vorig jaar heb afgerond. In §4.3 licht ik dit verder toe.



Figuur 14: Met 3D-printen een snellere ontwerpiteratie (Hayford & Sapienza, 2021)

## 4.2.1. Bijzonderheden printer Onyx One (FFF)

De Onyx One werkt volgens het principe Fused Filament Fabrication (FFF). Kort gezegd houdt dit in dat er alleen basismateriaal Onyx kan worden verwerkt. De specificaties hiervan worden verder in deze § uiteengezet. Deze zijn opgehaald in: <https://markforged.com/3d-printers/onyx-one>. (Markforged, 2022). Via deze link is de data sheet te downloaden: [F-PR-4011.pdf](#)



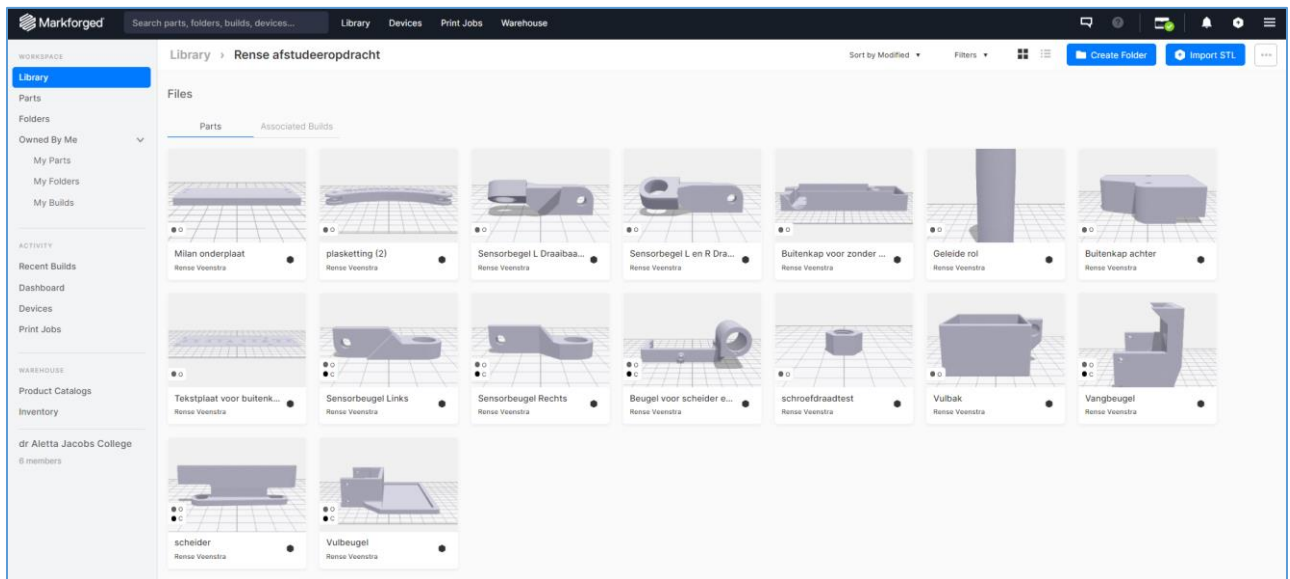
Figuur 15: Het instapmodel Onyx One (Markforged, 2022)

### 4.2.1.1. Specificaties Onyx One 3D-printer

- Merk / type: Markforged / Onyx One 3D
- Werkbereik X, Y, Z: 320mm x 132mm x 154mm
- Repeteernauwkeurigheid: 0,1 – 0,2mm
- Productiesnelheden: Zie als voorbeeld figuren 2 en 3

### 4.2.1.2. Softwarematige aansturing

- Deze geschiedt d.m.v. een software-account <https://www.eiger.io/library> in de cloud, die zeer gemakkelijk te bedienen is. Een 3D-model getekend in een programma, zoals Solid Works, kan weg geschreven worden met de extensie **.STL**, die eenvoudig te importeren is in Eiger/Markforged. **Figuur 16** laat mijn bibliotheek zien, in Eiger, van de geïmporteerde onderdelen die ik getekend heb in Solid Works. In § 4.2.5 worden deze nader uitgewerkt.
- In het programma Eiger kan er bijvoorbeeld gekozen worden voor honinggraatstructuur, lineaire structuur of volledig gevuld. Laagdiktes zijn instelbaar.



Figuur 16: Bibliotheek met geïmporteerde onderdelen in Eiger (Markforged, 2023)

### 4.2.1.3. Specificaties filament Onyx

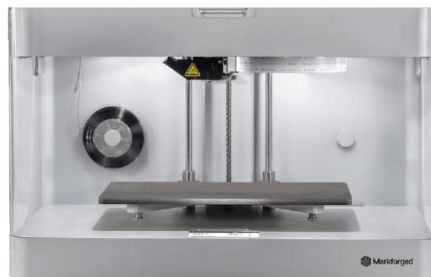
- Onyx is een composiet van PA6 en short cut-carbon fiber. Hierdoor is het niet alleen veel stijver dan standaard PA6, maar ook veel duurzamer en sterker. Ook heeft elk geprint product een perfecte zwart-satijnen finish door de toevoeging van het koolstof. Onyx is geschikt voor alle Markforged 3D printers en kan gebruikt worden in combinatie met alle Markforged CFF fibers (Markforged, 2022).
- Voor maximale treksterkte en belasting om zo onderdelen te produceren die sterker en duurzamer zijn dan aluminium.
  - Volgens de specificaties heeft het materiaal een treksterkte van 37 MPa. **Als je dit omrekent, komt dit overeen met 370kg/cm<sup>2</sup>** (Markforged, 2022).

### 4.2.2. Bijzonderheden printer Mark Two (CFF)

De Mark Two is in grote lijnen dezelfde printer, ware het niet dat een tweede nozzle versterkte composieten kan toevoegen. Zie rol links in figuur 17. Dit proces wordt Continuous Filament Fabrication (CCF) genoemd (Markforged, 2022).

In de afbeelding is links de spoel te vinden Carbonmateriaal. Het basismateriaal Onyx wordt extern in een dry box afgewikkeld. De Onyx One kan alleen het basismateriaal Onyx verwerken. De Mark Two kan versterkte vezels toevoegen, te weten Fiberglass, Carbon Fiber, Kevlar en HSHT Fiberglass (High Strength High Temperature). (Markforged, 2022).

De specificaties en bijzonderheden zijn opgehaald in: <https://markforged.com/3d-printers/mark-two>. (Markforged, 2022) Via deze site is een data sheet te downloaden: [F-PR-2027.pdf](https://markforged.com/3d-printers/mark-two)



Figuur 17 Markforged 3D-printer, type Mark Two (Markforged, 2022)

Uiteraard wordt de keuze van het toe te voegen composiet bepaald door de toepassing. Zo is Kevlar vele malen impactbestendiger dan Carbon.



Figuur 18: Verschillende toe te voegen composieten (Hayford & Sapienza, 2021)

### 4.2.3. Scholing: University Composites Training Program

In het kader van regionale samenwerking zijn er meerdere scholen, in onze regio en nabijgelegen regio's, die een printer van Markforged hebben aangeschaft. We hebben hier een voortrekkersrol in (Train de Trainer).

Daartoe heb ik de onlineopleiding "University Training Program", met een aansluitend online examen afgerond. In bijlage I is een samenvatting van de gehele opleiding opgenomen (Hayford & Sapienza, 2021). Bijlage G laat het mijn behaalde certificaat zien.

De inhoud van de opleiding wordt in figuur 19 kort uiteengezet, met daaronder de vertaling in Nederlands.



Markforged University Composites Training Program

Time to Completion: 4h 10m

Path Manager: Samantha Hayford

Date assigned: 03 Jan 2022

Due date: 20 Oct 2024

Path Components: 14 Courses, 1 Survey, 11 Lessons, 1 Test

Description: The Composites Training Program is designed to help you build and develop the skills necessary to take advantage of Markforged composite-reinforced 3D printing technology to accelerate and simplify your everyday engineering or technical work. In this three-part training program, consisting of Core, Essential, and Advanced Composites, your instructors will guide you as you explore the fundamental operating principles of Markforged composite 3D printing, develop your skills in Design for Additive Manufacturing (DfAM) and hone your intuition for identifying impactful applications of high-performance 3D printing in your operations. Program content includes lectures, real-world demos and case studies, guided tutorials in both Markforged's Eiger software and CAD, and much more.

Completion of this training program prepares you to take the Markforged Certified Additive Expert exam in Composites (MCAE-C), which will be administered at the end of formal instruction.

Figuur 19: Inhoud van de opleiding University Composites Training Program (Hayford & Sapienza, 2021)

#### Markforged University Composites-trainingsprogramma

Het Composites-trainingsprogramma is ontworpen om u te helpen de vaardigheden op te bouwen en te ontwikkelen die nodig zijn om te profiteren van Markforged composiet versterkte 3D-printtechnologie om uw dagelijkse technische of technische werk te versnellen en te vereenvoudigen. In dit driedelige trainingsprogramma, bestaande uit Core, Essential en Advanced Composites, zullen uw instructeurs u begeleiden bij het verkennen van de fundamentele werkingsprincipes van Markforged composiet 3D-printen, het ontwikkelen van uw vaardigheden in Design for Additive Manufacturing (DfAM) en het aanscherpen van uw intuïtie voor het identificeren van impactvolle toepassingen van high-performance 3D-printen in uw activiteiten. De inhoud van het programma omvat lezingen, real-world demo's en casestudy's, begeleidde tutorials in zowel Markforged's Eiger-software als CAD, en nog veel meer.

De voltooiing van dit trainingsprogramma bereidt u voor op het Markforged Certified Additive Expert-examen in Composites (MCAE-C), dat zal worden afgenomen aan het einde van de formele instructie.

Vertaling van figuur 19 (Hayford & Sapienza, 2021)

Uiteraard was de opleiding een welkome aanvulling voor ontwerpproces en kan dit dienen als opleiding van collega's van andere scholen, in het kader van "Train de Trainer".

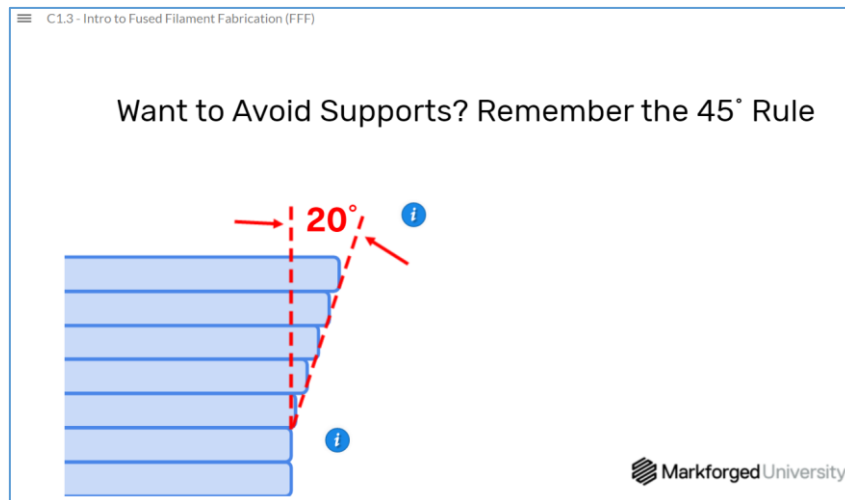
In de navolgende paragrafen zijn een paar principes en regels m.b.t. tot 3D-printen opgenomen. In de opleiding is uiteraard veel meer te vinden, maar dit zijn belangrijkste aspecten.



### 4.2.3.1. Een paar 3D-print principes c.q. regels

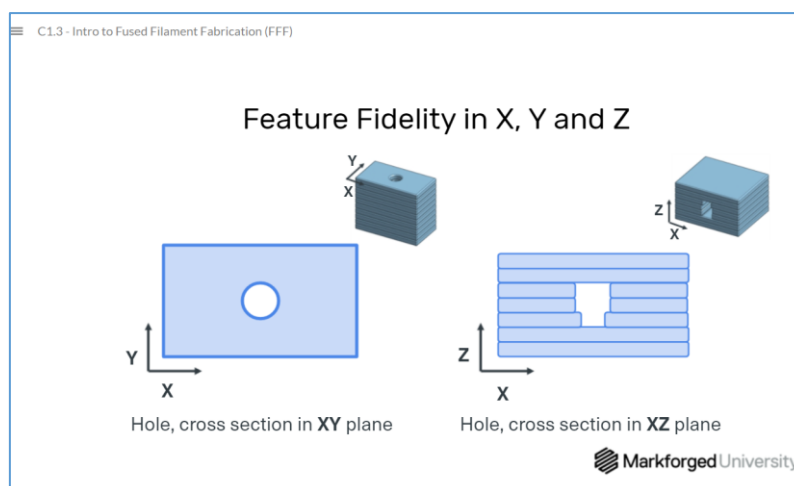
Om verspilling tegen te gaan is het van belang dat bij het ontwerp rekening wordt gehouden met de beperkingen en mogelijkheden bij 3D-printen. Het vergt dus een wijze van denken.

Zo kan gebruik van ondersteuningsmateriaal vermeden worden als de hoek in Z-richting  $\leq 45^\circ$



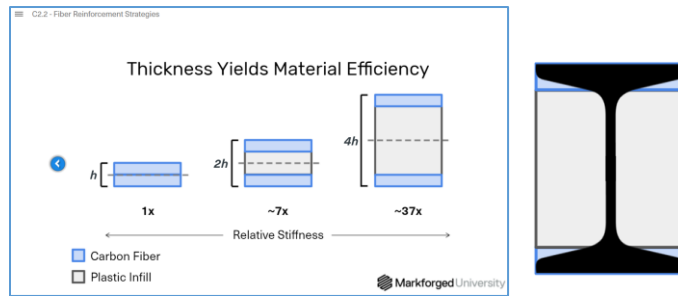
Figuur 20: Bij hoek  $\leq 45^\circ$  geen ondersteuningsmateriaal nodig (Hayford & Sapienza, 2021)

Een volgend aspect waar rekening mee dient te worden is dat de printer in laagjes/druppeltjes het product opbouwt, waardoor de Z-richting op het print-bed rekening worden gehouden dat de Z-richting de zwakste is. Het print-materiaal moet dan ook als een **anisotroop** beschouwd worden. De eigenschappen (in dit geval treksterkte als belangrijkste) zijn *niet* in iedere richting dezelfde zijn.



Figuur 21: Z-richting door anisotropie het zwakst (Hayford & Sapienza, 2021)

Verder is in figuur 18 te zien dat de composieten in de buitenste lagen geïmpregneerd is, het zogenaamde sandwich panel. Dit noemen we concentrisch leggen (in Engels: Continuous). Dit bespaart versterkt materiaal, terwijl de constructie stijf blijft. Ditzelfde principe wordt immers ook toegepast bij IPE- en HEB-balken. Ook kan er isotropisch gelegd worden (m.a.w. helemaal gevuld), maar kost veel meer versterkt materiaal.



Figuur 22: Voordelen van sandwichvorm: materiaalbesparing (Hayford & Sapienza, 2021)

In bijlage A heb ik een voorbeeldberekening van een traagheidsmoment van een balk en een I-vorm toegevoegd. Als naslagwerk heb ik het studieboek “Sterkteleer” (Bakker, 2005) geraadpleegd. Dit heb ik ook gedaan om mijn werktuigbouwkundige kennis weer eens op te frissen.

Ik kan verder op de materie ingaan maar zou het hierbij willen laten, omdat het m.i. niet meer toevoegt aan het ontwerp dossier. Boodschap is duidelijk: besparing van materiaal en net zo sterk.

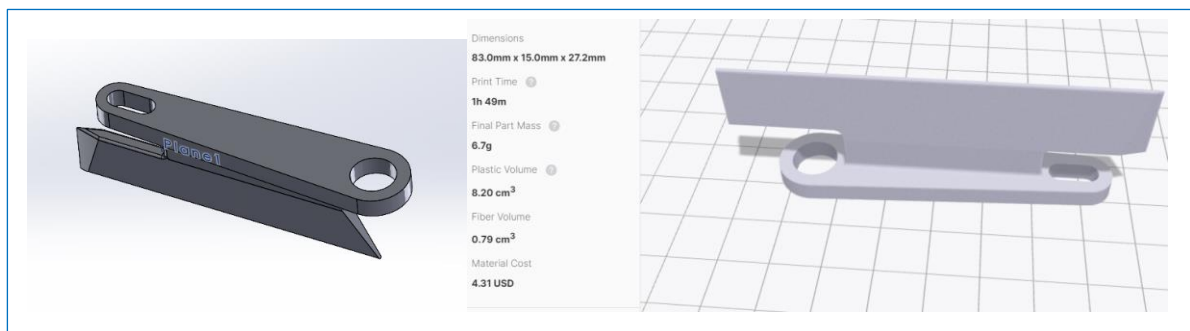
Zoals al eerder genoemd zijn er verder nog talloze bijzonderheden, regels etc. te noemen, m.b.t. 3D-printen. In bijlage I is een samenvatting opgenomen van de gehele opleiding “Markforged University Composites Training Program”.

#### 4.2.4. Overzicht van 3D-geprinte CAD-onderdelen

In deze paragraaf is het overzicht opgenomen van alle onderdelen die ik getekend heb met Solid Works. Na gereed kunnen deze gemakkelijk weggeschreven worden als en STL-file, die in de cloud programma van Markforged (Eiger) gedownload kan worden.

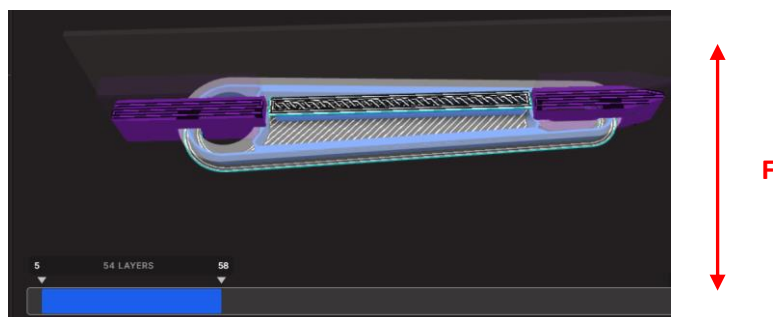
In dit programma kan keuzes worden gemaakt in printrichting, wel of niet toevoegen van versterkt materiaal, wanddiktes, vulwijze en dichtheid, e.d. In de komende afbeelding is links het CAD-model te zien en rechts een screenshot uit het printprogramma, waarin o.a. de materiaalkosten (USD) zijn weergegeven.

##### De sorteerschuiif:



Figuur 23 SW-part en printbestand van de schuif

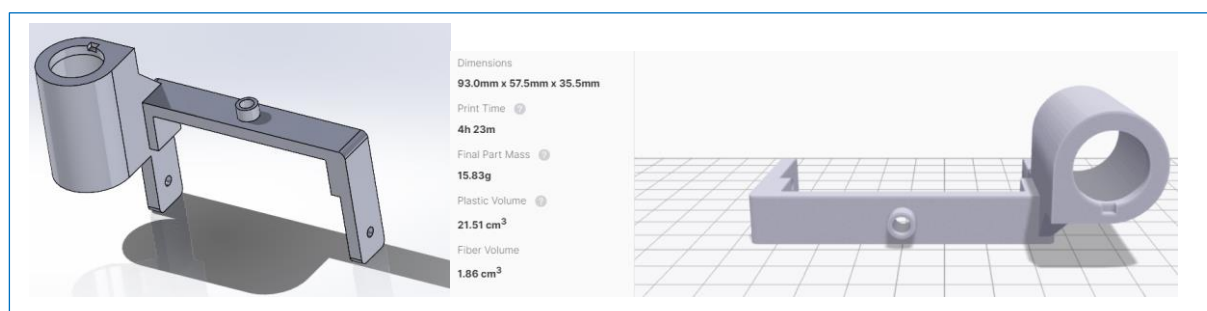
De schuif is geprint met Onyx als basismateriaal en versterkt met carbon, in concentrisch (sandwich) gelegd in de blauw aangegeven lagen 5 tot en met 58. Ook kan er gekozen worden



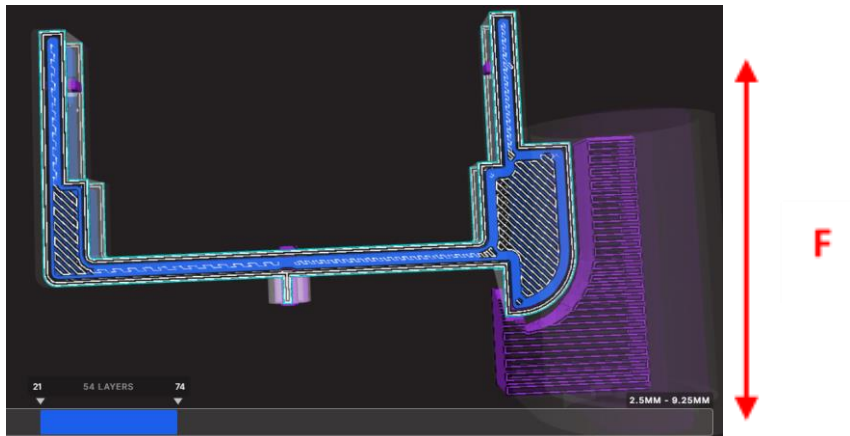
Figuur 24: Inwendige structuur van continue aangebracht carbon.

Dit laat zien dat printrichting wordt bepaald door de belastingsrichting.

##### Beugel voor schuif en lamp:



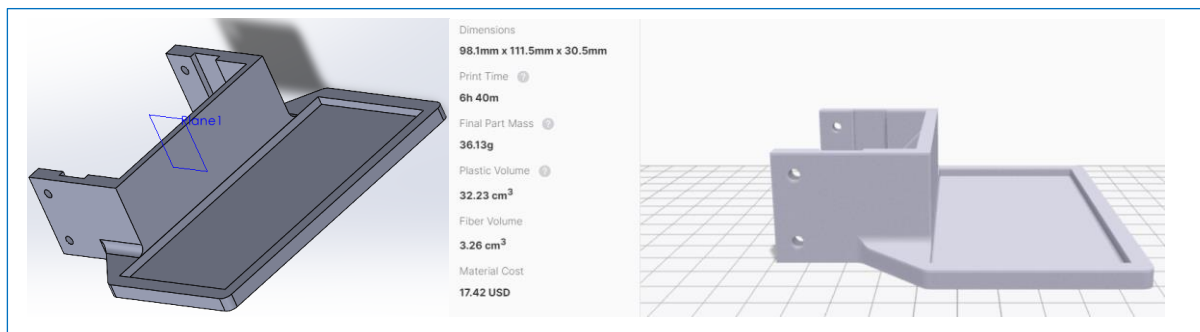
Hier hetzelfde principe. De belasting richting is niet zo zeer functioneel bepaald, maar meer “gebruiker” bepaald.



Figuur 25: Concentrische ligging carbon

### Laadplateau:

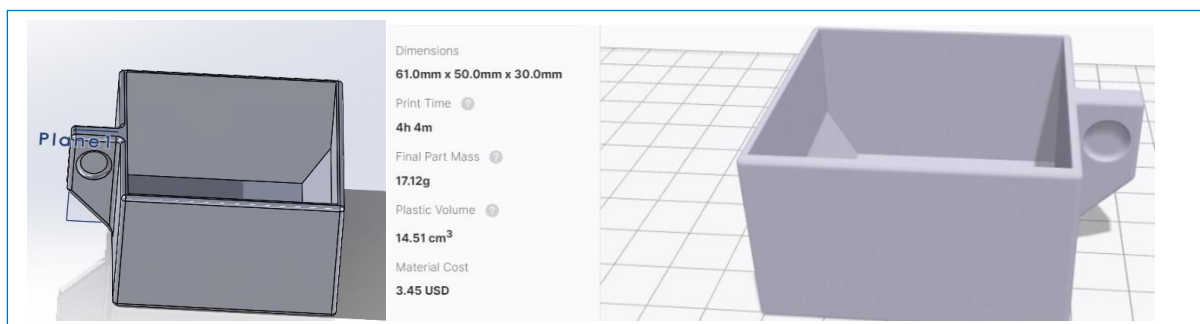
Dit onderdeel komt aan de voorzijde van de afsorteerder te zitten, waarop de 2 vulbakjes geplaatst kunnen worden.



Figuur 26: Laadplateau

### Vulbak:

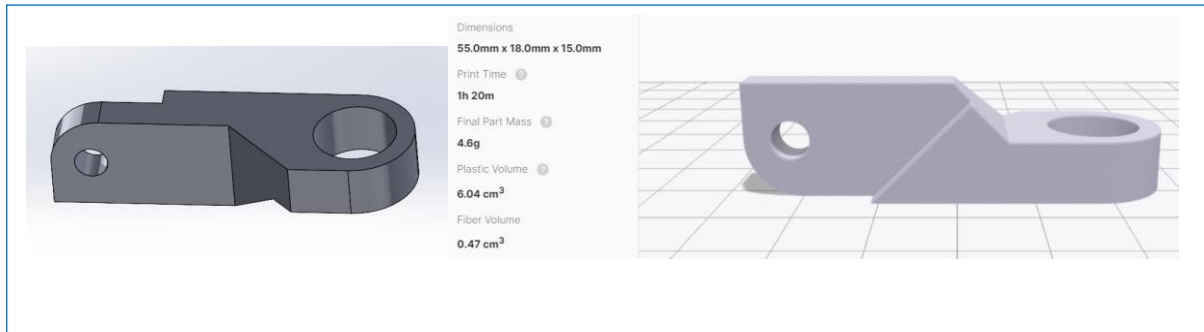
Ook alleen met Onyx geprint. 2 Bakjes zijn nodig die geplaatst kunnen worden op het laadplateau van de afvoersorteerder.



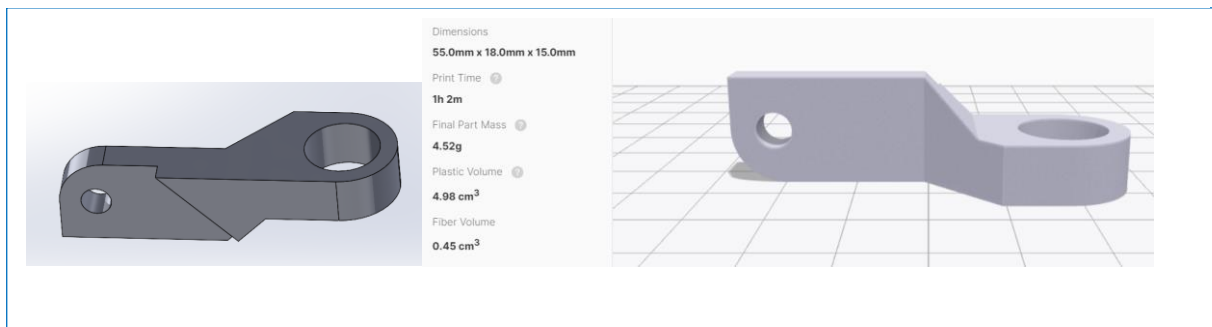
Figuur 27: Vulbak

### Sensorbeugel Links en Rechts:

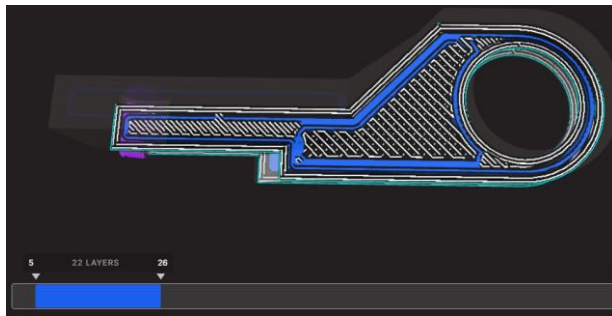
In het programma van eisen heb ik gesteld dat de sensoren in hoogte verstelbaar moeten zijn. Dit om de bakjes makkelijk te kunnen legen. In de morfologische kaart kwam naar voren dat een scharnierende de meest eenvoudige (en dus beste) oplossing is.



Figuur 28: Sensorbeugel Links



Figuur 29: Sensorbeugel Rechts



Figuur 30: Carbon continu gelegd

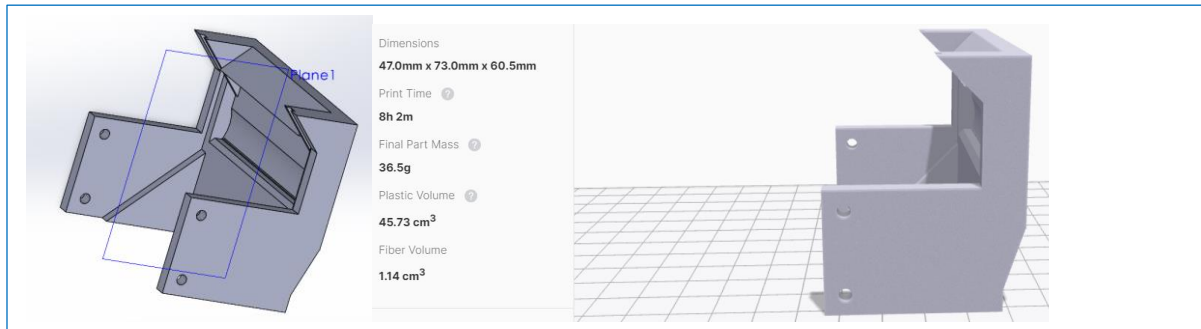
Hier hetzelfde principe. De belasting richting is niet zo zeer functioneel bepaald, maar meer “gebruiker” bepaald.

**Verder heb ik van dit onderdeel een 2D-tekening gemaakt, die opgenomen is in bijlage B.**

**Niet van alle onderdelen heb ik werktekeningen gemaakt, omdat het m.i. niet echt wat toevoegt. Kwestie van keuzes maken, omwille de tijd. De CAD-modellen blijven sowieso in de cloud bewaard.**

### **Opvangbeugel achter:**

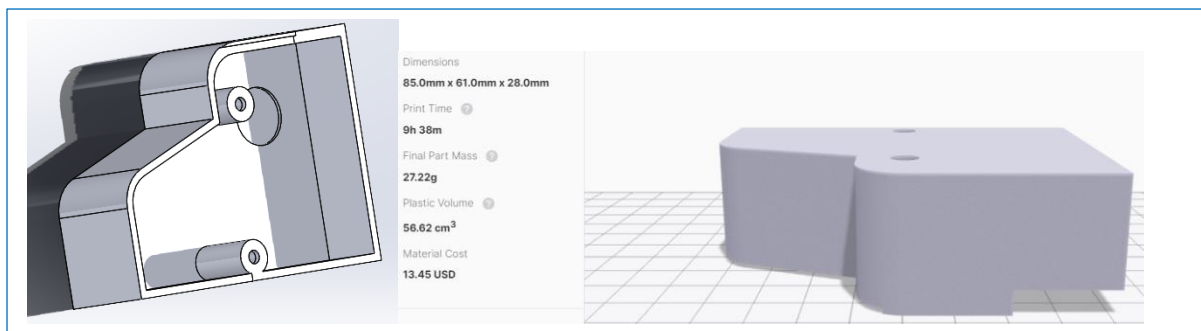
Om te voorkomen dat de moertjes aan begin van de transportband vallen, is deze vangbeugel gerealiseerd.



Figuur 31: Opvangbeugel

### **Afschermkap:**

In het programma van eisen werd de afscherming, van welke overbrenging dan ook, als vaste eis beschouwd. Daartoe is dit kapje gerealiseerd, die de leerling moet beschermen tegen de gekozen tandriemoverbrenging.

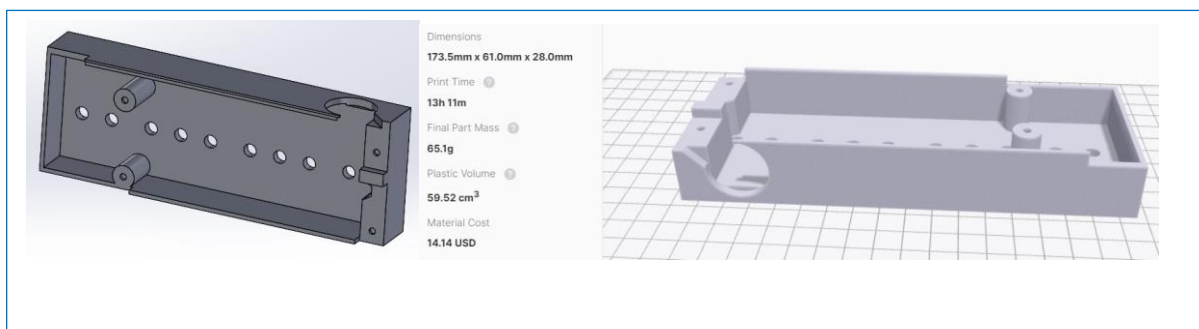


Figuur 32: Afschermkap aandrijving

Ook hier is alleen Onyx gebruikt.

### **Buitenkap voor aansluiten:**

Deze kap wilde in aanvankelijk met holle zijde naar beneden printen, om tekst aan bovenzijde te kunnen realiseren. Dit zou veel ondersteuningsmateriaal hebben gekost.



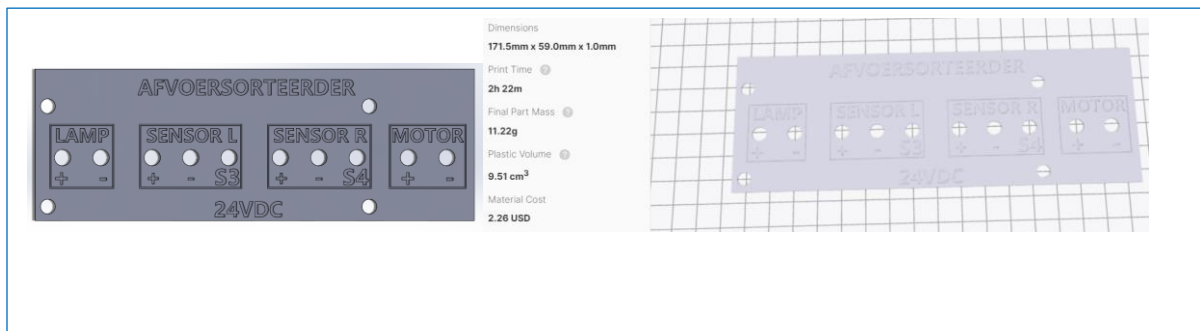
Figuur 33: Buitenkap voor aansluiten



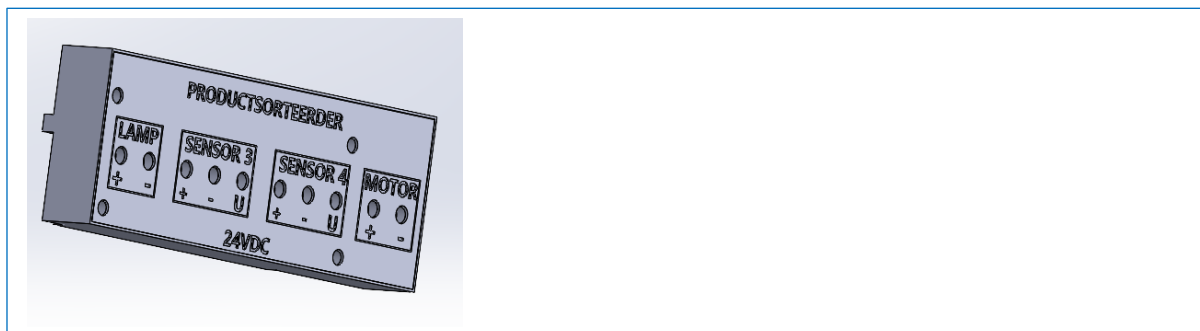
Daarom koos ik voor de volgende oplossing:

- Buitenkap op de kop printen zonder tekst.
- Tekstplaat printen.
  - Bij begin printen pauzeren en lakstift de tekst witten.
  - Verder printen.
- Daarna verlijmen met loctite.

Hiermee kon ik €20,- aan materiaal besparen.



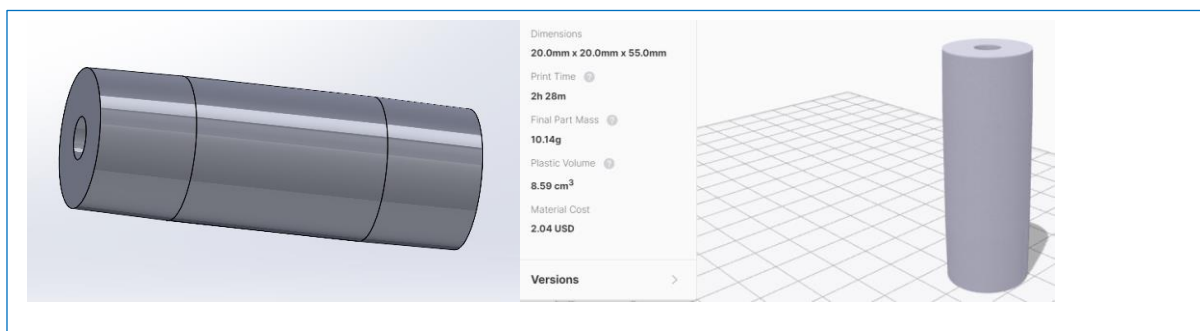
Figuur 34: Tekstplaat voor buitenkap



Figuur 35: Assembly van de complete buitenkap voor aansluiten

### Geleide- en aandrijfrol:

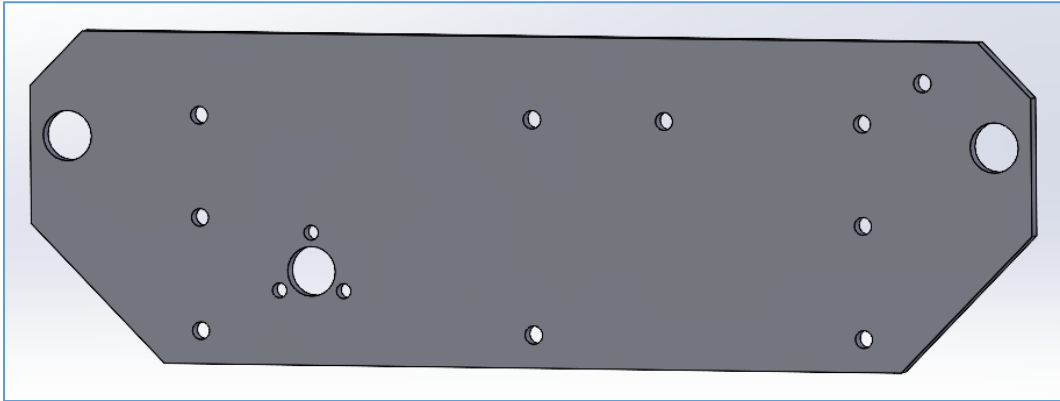
Hierop zitten wel rechten van Brink Techniek BV, maar we zouden deze kunnen printen voor €2,-. Inkoopsprijs is €9,50



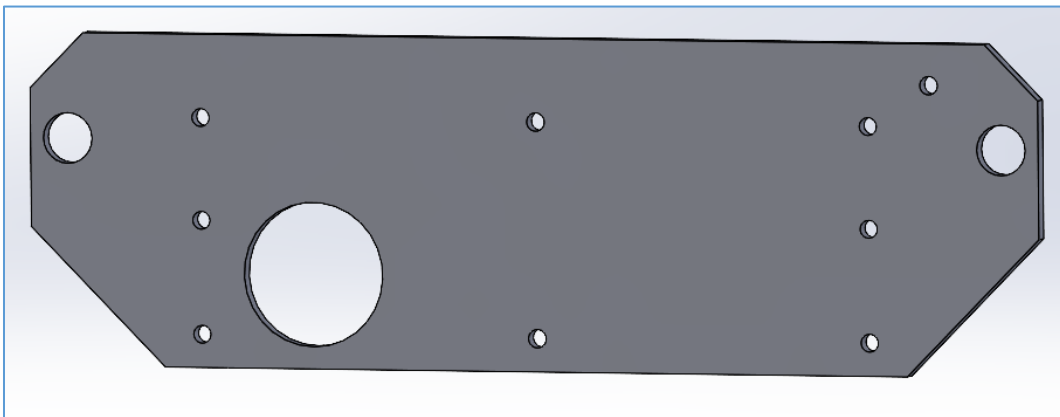
## 4.2.5. Overzicht van overige maaddelen

### Linker en rechter zijframe:

Deze zijn gemaakt uit aluminiumplaat van 3mm.



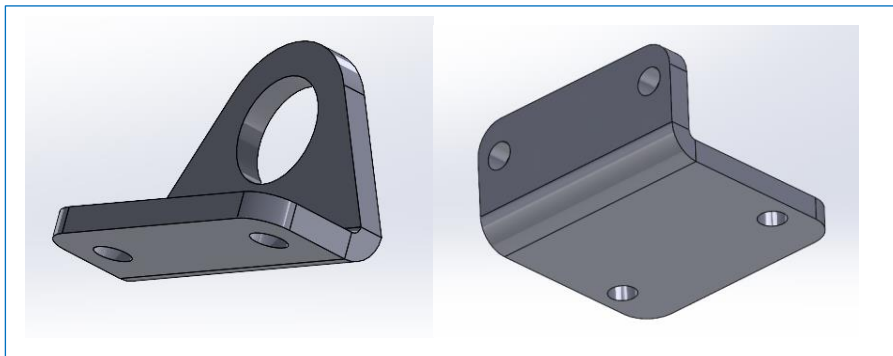
Figuur 36: Zijframe Links



Figuur 37: Zijframe Rechts

### Ophanging / bevestiging van dubbelwerkende luchtcilinder:

Deze twee onderdelen zijn gemaakt uit senzimir verzinkte plaat van 3mm en zijn t.b.v. het bevestigen van de dubbelwerkende cilinder op het linker zijframe



Figuur 38 T.b.v. ophanging dubbelwerkende luchtcilinder

### **Geleide- en lagerbusjes:**

Verder heb ik een aantal messingbusjes gedraaid, voor:

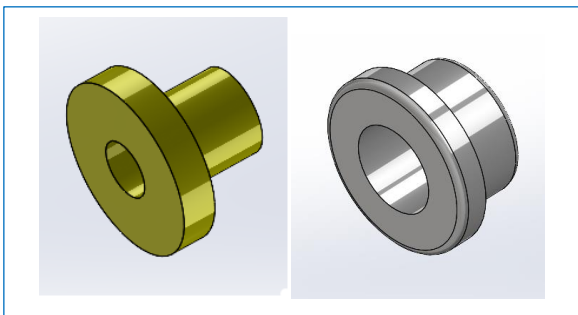
- Draaibare bevestiging van de schuif aan dubbelwerkende cilinder.
- Draaibare bevestiging van de sensorhouders.

Dit om “losdraaien” tijdens gebruik te voorkomen.

Rechts in de afbeelding is een glijlager te zien 6x9x6 voor lagering aandrijf- en geleide-rol. Deze heb ik weliswaar getekend, maar is ingekocht bij Brink Techniek BV.

**Verder heb ik van dit onderdeel een 2D-tekening gemaakt, die opgenomen is in bijlage B.**

**Niet van alle onderdelen heb ik werktekeningen gemaakt, omdat het m.i. niet echt wat toevoegt. Kwestie van keuzes maken, omwille de tijd. De CAD-modellen blijven sowieso in cloud bewaard.**

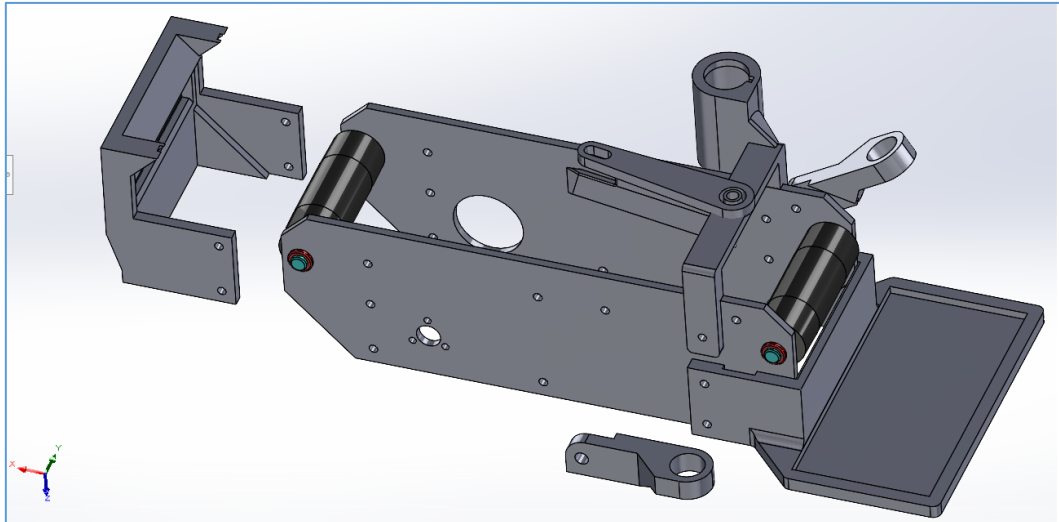


*Figuur 39 Messingbus en PA-66 lagerbus.*

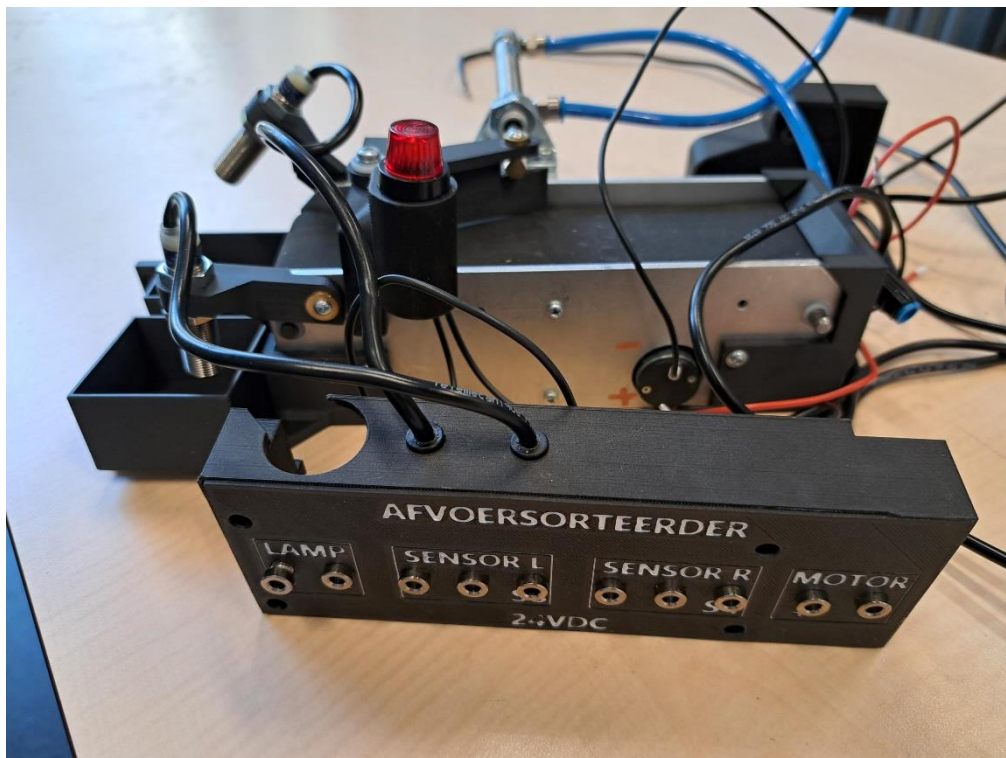
#### 4.2.6. De assemblage (assembly)

Nadat alle onderdelen vervaardigd en ingekocht zijn, kon ik eindelijk starten met het assembleren.

De afbeelding laat een (gedeeltelijke) assembly in Solid Works zien. Verder heb ik de resterende tijd aangewend om de afvoersorteerder fysiek te assembleren.



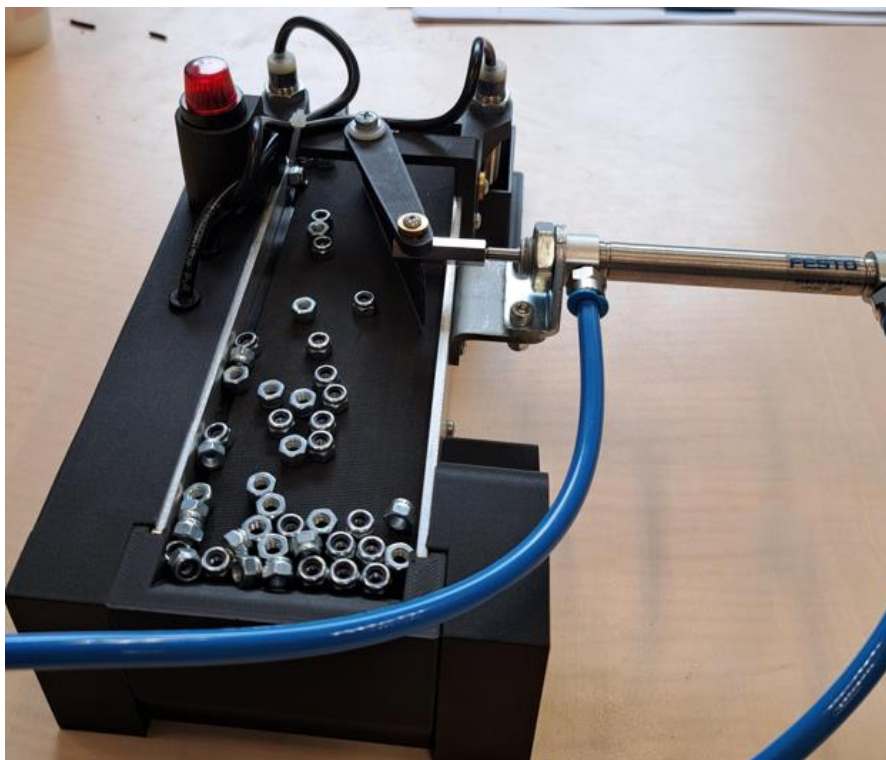
*Figuur 40: Gedeeltelijke assembly in SW, in wording.*



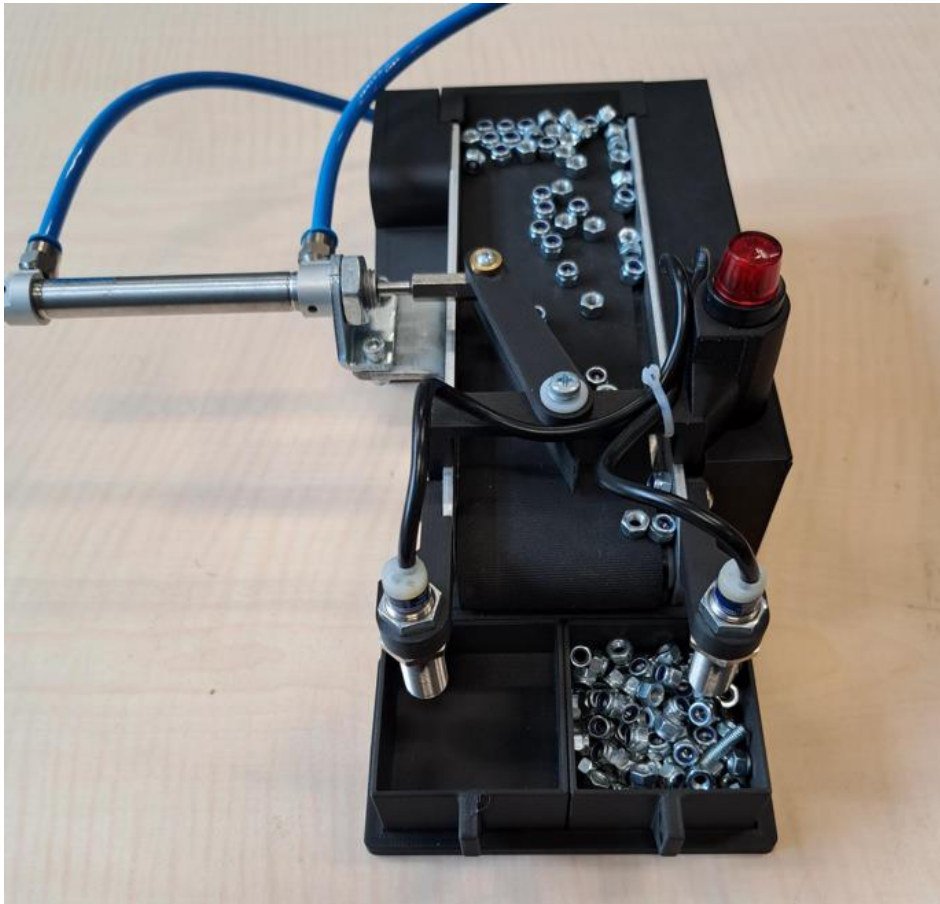
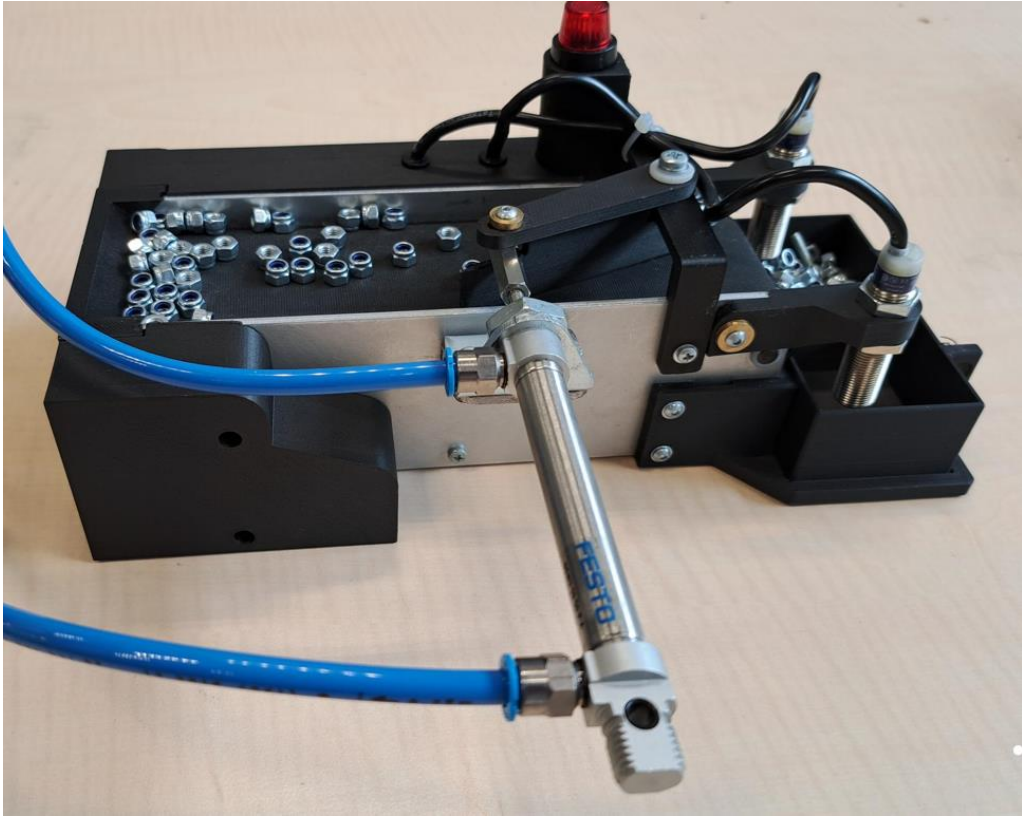
*Figuur 41: Fysieke assemblage in progressie*

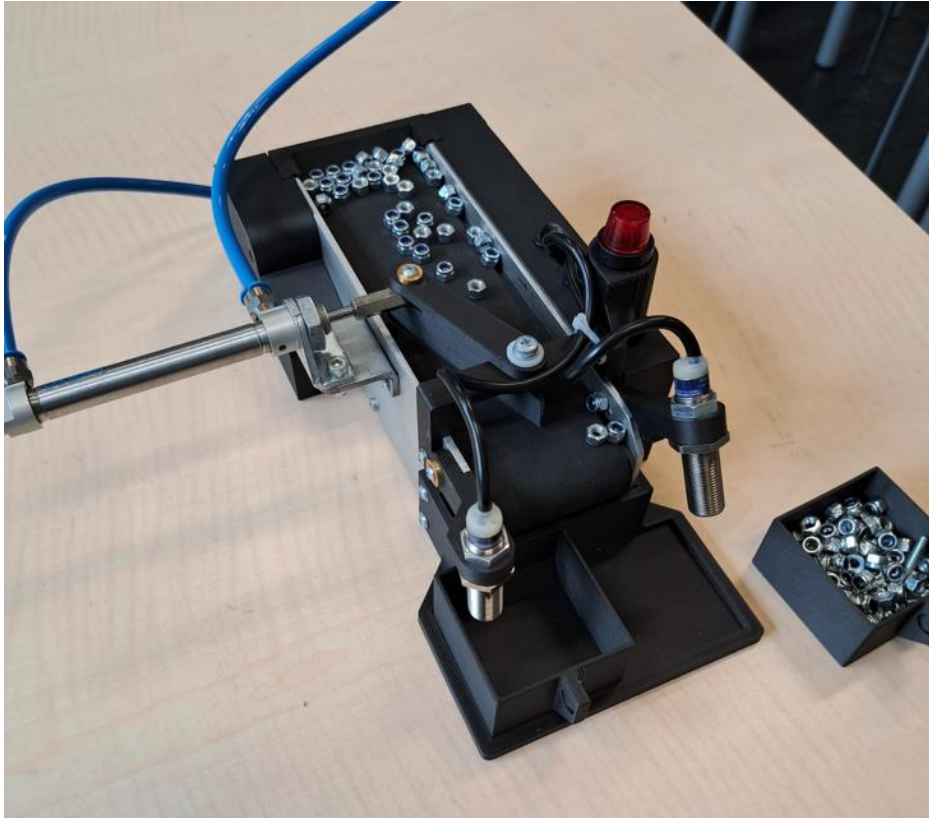
#### 4.2.6.1. Foto's van gereed product

Bijgaand een fotocollage van het gereede product. De werking een aansluiting te zien in het filmpje: [Filmpje Afvoersorteerder](#)









Filmpje Afvoersorteerder

### 4.3. Complete stuklijst en kosten

Artikel	Benaming	Leverancier / gemaakt door	Aantal	Eenheidsprijs	Totaal
	Schuif, 3D-geprint	Rense Veenstra	1	€ 4,31	€ 4,31
	Beugel voor schuif en lamp, 3D-geprint	Rense Veenstra	1	€ 10,68	€ 10,68
	Laadplateau, 3D-geprint	Rense Veenstra	1	€ 17,42	€ 17,42
	Vulbak, 3D-geprint	Rense Veenstra	2	€ 3,45	€ 6,90
	Sensorhouder R, 3D-geprint	Rense Veenstra	1	€ 2,52	€ 2,52
	Sensorhouder L, 3D-geprint	Rense Veenstra	1	€ 2,52	€ 2,52
	Vangbeugel achter, 3D-geprint	Rense Veenstra	1	€ 14,28	€ 14,28
	Afschermkap, 3D-geprint	Rense Veenstra	1	€ 13,45	€ 13,45
	Buitenkap voor zonder tekst, 3D-geprint	Rense Veenstra	1	€ 14,45	€ 14,45
	Tekstplaat voor buitenkap, 3D-geprint	Rense Veenstra	1	€ 2,26	€ 2,26
	Geleiderol, 3D-geprint	Rense Veenstra	1	€ 2,04	€ 2,04
	Geleidebusje, gedraaid uit messing,	Rense Veenstra	3	€ 2,00	€ 6,00
	Ophanging voor dubbelwerkende cilinder, zincorplaat 2mm	Rense Veenstra	1	€ 1,50	€ 1,50
P02.03.300	Glijplaat 8mm PE 60mm Breed PE Zwart	Brink Techniek BV	1	€ 7,00	€ 7,00
P14.01.020	MAT-02H Elastische machineband LNGT 407 mm x BRDT 55 mm	Brink Techniek BV	1	€ 29,00	€ 29,00
P14.01.030	SYNCHROFLEX TANDRIEM 3326AT3/150W 6AT3/150	Brink Techniek BV	1	€ 7,00	€ 7,00
P14.01.031	SYNCHROFLEX RIEMSCHIJF 33110AT3/15-N2 10AT3/15-N2	Brink Techniek BV	2	€ 14,00	€ 28,00
P05.03.008.0610	Glijlagers 6x9x6, Materiaal: nylon-66 (PA-66)	Brink Techniek BV	5	€ 7,40	€ 37,00
P11.04.002	LAMP E10 24V 50MA E10 1,2W 404126	Brink Techniek BV	1	€ 1,80	€ 1,80
P11.02.001	Signaallamp armatuur Rafi rood lens	Brink Techniek BV	1	€ 3,95	€ 3,95
P09.50.008	Inductieve sensor type Bi1,5U-EG08-AP6XSchakelafstand 1,5mm	Brink Techniek BV	2	€ 45,00	€ 90,00
	Diverse schroeven, moeren etc.	Catalogusmateriaal	20	€ 0,05	€ 1,00
	Duurtule, rubber Ø 6mm	Catalogusmateriaal	2	€ 0,02	€ 0,04
P13.03.001	DC-Motor 24V + aandrijving 84:1	Brink Techniek BV	1	€ 165,00	€ 165,00
P65.01.0850D	DSNU-8-50-P-A DUBBELW.CILINDER	Brink Techniek BV	1	€ 21,25	€ 21,25
P03.01.17.006	Assen staal 6 mm.	Brink Techniek BV	2	€ 9,00	€ 18,00
P07.03.009	Blanke stekkerbus 4 mm	Brink Techniek BV	10	€ 1,00	€ 10,00
	Diverse aansluitdraden	Catalogusmateriaal	4	€ 0,03	€ 0,12
P65.09.003	LBN-8/10 ONDERDEEL VOOR SCHARNIERBEVESTIGING	Brink Techniek BV	1	€ 3,30	€ 3,30
P65.09.002	Voetbevestiging HBN-8/10X2	Brink Techniek BV	1	€ 3,00	€ 3,00
	<b>Totaal</b>				<b>€ 523,79</b>

De daadwerkelijke kosten niet uit de hand gelopen. In mijn PVA had ik €500,- begroot.



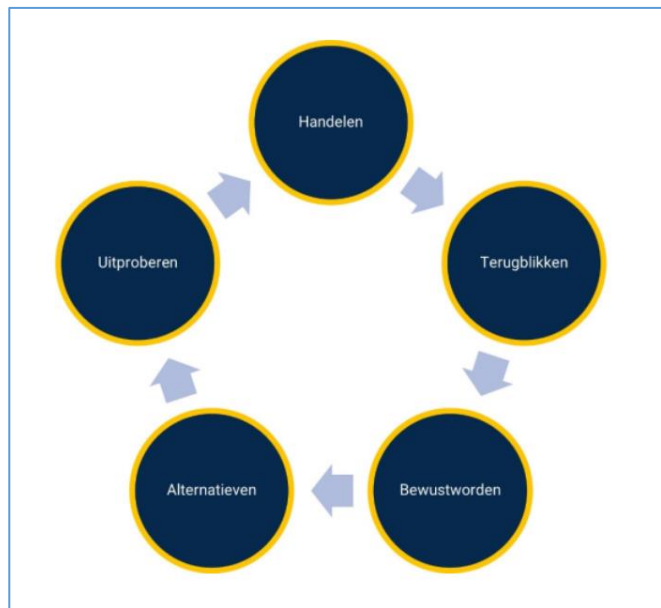
## 5. Slot en reflectie volgens het model van Korthagen

Een belangrijk aspect in het uitvoeren van de integratieve opdracht is terugkijken op het hele proces. Wat heb ik ervan geleerd? Hoe zou ik zaken een volgende keer anders aanpakken? Maar nog belangrijker: wat heb ik eraan in de dagelijkse praktijk?

Daarom heb ik gekozen om op mijn handelen te reflecteren volgens het model van Korthagen

(<https://www.scriptium.nl/model-van-korthagen/>)

Vaak zie je door terug te kijken pas in hoe het je afging, in plaats van op het moment zelf. Zonder te reflecteren zou je daar niet snel achter zijn gekomen. Het is dus zeer waardevol om terug te kijken op je handelen (Scriptium Excelente Onderwijshulp, 2014).



Figuur 42: Het model volgens Korthagen (Scriptium Excelente Onderwijshulp, 2014)

Ik heb gekozen voor dit model Het model van Korthagen omdat dit een reflectiecirkel. Na stap 5 kom je namelijk automatisch terug bij stap 1. Zo kun je het proces van reflectie opnieuw doorlopen. Hieronder zie je een handige visualisatie van het model (Scriptium Excelente Onderwijshulp, 2014):

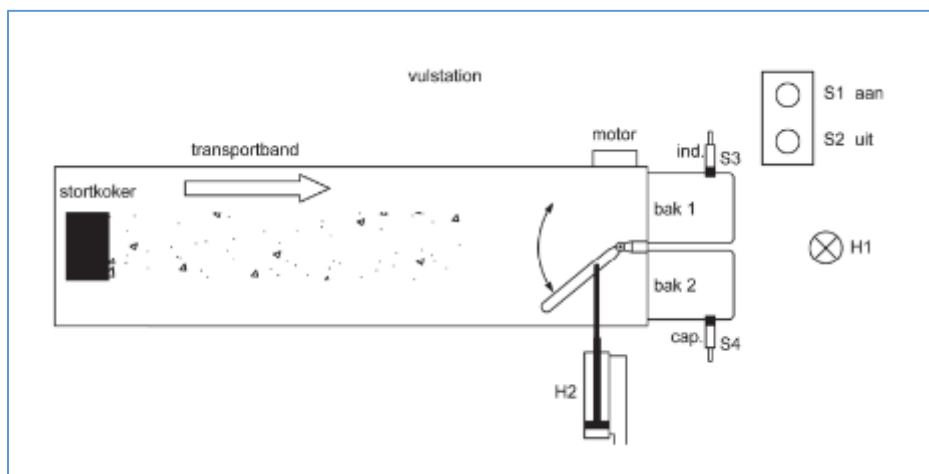
<b>Handelen</b>	Wat was de situatie? Wat wilde ik testen? Wat was mijn doel met de handeling? Wat waren de concrete acties die ik in die situatie heb ondernomen? Wat was het gevolg van mijn acties?
<b>Terugblikken</b>	Wat wilde ik doen? Wat zag ik? Wat heb ik gedaan? Wat dacht ik toen? Wat voelde ik op dat moment?
<b>Bewustwording</b>	Wat betekent het voor mij? Wat is het probleem? Wat heeft het probleem veroorzaakt?
<b>Alternatieven</b>	Welke alternatieven zie ik om het probleem op te lossen? Wat zijn de voor- en nadelen van die alternatieven? Wat wil ik de volgende keer anders aanpakken?
<b>Uitproberen</b>	Wat wil ik proberen? Wat wil ik uitproberen? Waar wil ik op letten?

(Scriptium Excelente Onderwijshulp, 2014)

## 5.1. Stap 1: Handelen

De werkelijke (hetzij onbewuste) opdrachtgevers zijn onze leerlingen. Ze geven dikwijls aan geen beeld te hebben waarom en hoe besturingstechniek, in het bedrijfsleven, wordt toegepast. Na een aantal formatieve opdrachten, zoals elektropneumatiek, programmeren en aansluiten van de EasyRelais, moet de leerlingen de summatieve PTA-opdracht is de zogenaamde “Afvalsorteerder” voltooien. Dit is een opdracht waarvoor rechtstreeks het blauwe onderdeel D van het CSPE 2019 wordt gebruikt. [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

Ondanks afbeelding in figuur 3 en de opdrachtomschrijving is het voor de leerlingen lastig zich een voorstelling te maken hoe zo iets er in het echt zou kunnen uitzien en werken.



Figuur 3 De afvalsorteerder (College voor Toetsen en Examens, 2019) (bron CSPE 2019, onderdeel D Blauw)

Het programmeren wordt vaak als lastig ervaren en de toepassingen in het bedrijfsleven, zijn voor hen veelal abstract. Met een apparaat, die ook daadwerkelijk doet, wat in de opdracht staat omschreven, zal het nut duidelijk worden en de materie beter bekliven. Dit blijkt ook uit de eindgesprekken, die aan de opdracht verbonden zijn.

## 5.2. Stap 2: Terugblikken

Tijdens het uitwerken van mijn dossier had ik (onbewust) verzuimd duidelijk aan te geven dat het een CSPE-opdracht betrof die in ons PTA is opgenomen. Tijdens het Criterium Gericht Interview (CGI), in juni 2023, met de heren H. Spaan en H. Goes van Windesheim werd dit nadrukkelijk naar voren.

Daarnaast was de bronvermelding niet op orde.

Ook was het pijnlijk dat ik op de laatste dag nog het verplichte deel in mijn portfolio <https://maken.wikiwijs.nl/?id=15&arrangement=198110> nog gecomplementeerd moest worden met het deel “Leeruitkomsten”.

Al met al was het gevolg dat opdracht werd afgewezen. Ik voelde me hierdoor behoorlijk bezwaard en verweet mezelf naïef te hebben gehandeld, zoals in bijgaande mail te lezen is:

### 5.3. Stap 3: Bewustwording

De afwijzing betekende dat het dossier moest worden herschreven en een volgend CGI pas in het volgende schooljaar aangevraagd kon worden.

Het probleem is ontstaan dat ik was te veel op de eindoplossing gericht was. Ik realiseer me dat het best lastig is om out of de box te denken; meerdere mogelijkheden onderzoeken.

Verder had ik me te weinig in de APA-normering verdiept en opdrachtomschrijving, m.b.t. leeruitkomsten verkeerd geïnterpreteerd c.q. niet goed gelezen.

Verder had ik meer trots moeten uitstralen en een filmpje moeten uploaden met bijvoorbeeld een leerling die de opdracht had voltooid en de werking demonstreerde.

### 5.4. Stap 4: Alternatieven

In het aangepaste dossier moet duidelijk naar voren komen dat CSPE-opdracht als uitgangspunt is genomen. Dit heeft tot gevolg dat de vast, variabele eisen herzien moeten worden en aansluitend een aanpassing van o.a. de morfologische kaart.

Gelukkig kreeg ik de gelegenheid om het hetzelfde eindproduct (Afvoersorteerder) en delen van het oude dossier te gebruiken.

### 5.5. Stap 5: Uitproberen

Het gevolg is dat ik bijgaand dossier heb aangepast en voornemens ben om een filmpje [https://www.youtube.com/results?search\\_query=Rense+Veenstra](https://www.youtube.com/results?search_query=Rense+Veenstra) up te loaden met een leerling die de opdracht heeft voltooid en de werking demonstreert.

Ik heb ervan geleerd een eventuele volgende keer me meer te verdiepen in de opdrachtomschrijving en correctere te werken volgens de APA-normering, **ook bij het ontwikkelen en uitwerken van nieuw lesmateriaal!**

### 5.6. Is het doel bereikt?

Toen de afvoersorteerder in wording was heb ik leerlingen het laten zien. Ook heb ik ze even laten stoeien met het halffabrikaat. Aansluiten motor en testen van de werking e.d. Daar kwamen nog wat dingetjes uit. Ontzettend leuk dat ze dan meedenken en er bruikbare tips naar boven kwamen.

De leerlingen waren oprecht geïnteresseerd en vroegen nadien regelmatig hoe het met mijn “projectje” ging en wanneer ze de opdracht ermee kunnen uitvoeren.

Alhoewel dat (op het moment van dit schrijven) de opdracht nog niet is ingezet, mag ik concluderen dat de afvoersorteerder tot de verbeelding zal spreken voor de rest van de leerlingen. Ook een aantal BB-leerlingen waren geïnteresseerd en wil hen daarom de gelegenheid geven deze uit te voeren als verdieping (het is immers een KB-opdracht).

Verder zijn de daadwerkelijke kosten van €538,- niet uit de hand gelopen. In mijn PVA had ik €500,-

In bijgaand filmpje is de aansluiting en werking van de afvoersorteerder te zien:

[https://www.youtube.com/results?search\\_query=Rense+Veenstra](https://www.youtube.com/results?search_query=Rense+Veenstra)

## 5.7. Dankbetuigingen

### Graag wil ik bedanken:

- De heren Evert Draaijer en Joost Brink van Brink Techniek BV hartelijk bedanken voor het meedenken, brainstormen en advies.
- Mijn directe PIE-collega's voor hun meedenken, brainstormen, advies en hun enthousiasme voor het uitwerken van de meer aansprekende opdracht:
  - Shurensly Chirino (technisch onderwijsassistent)
    - Chris Toren (docent PIE)
    - Ibrahim Uzel (docent PIE)
    - Rolf Ahlers (technisch onderwijsassistent)
    - Monika Smit (deelschoolleider vmbo)
- De begeleidende docenten:
  - Henk Spaan, Harrie Goes en Michel Greeven, voor hun heldere en pragmatische begeleiding. Altijd was er snel antwoord op terugbelverzoek en mail e.d., zodat ik weer snel verder kon.

## Verwijzingen

Bakker, C. (2005). *Sterkteleer*. Baarn: HB Uitgevers.

College voor Toetsen en Examens. (2019). *Produceren, installeren en energie vmbo kb*. Opgehaald van Examenblad.nl: [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

Grit, R. (2015). *Projectmanagement*. Groningen/Houten, The Netherlands: Noordhoff Uitgevers bv.

Hayford & Sapienza, S. a. (2021, December 23). Markforged University Composites Training Program. Waltham, Massachusetts, Greater Boston Area, United States of America. Opgehaald van <https://markforged.showpad.biz/webapp2/home>

Markforged. (2022, August 8). *Mark Two*. Opgehaald van Markforged: Industrial Additive Manufacturing Platform: <https://markforged.com/3d-printers/mark-two>

Markforged. (2022, July 20). *Onyx One*. Opgehaald van Markforged: Industrial Additive Manufacturing Platform: <https://markforged.com/3d-printers/onyx-one>

Markforged. (2023, April). *Log in to your Markforged account*. Opgehaald van Markforged Login: <https://www.eiger.io/signin>

Scriptium Excelente Onderwijshulp. (2014). *Het Model van Korthagen – Reflecteren op je gedrag in 5 stappen*. Opgehaald van Scriptium - Excellente onderwijshulp: <https://www.scriptium.nl/model-van-korthagen/>

Verhoeven, N. (2018). *Wat is onderzoek?* Amsterdam: Boom uitgevers Amsterdam.

Zeiler, W. (2014). *Basisboek Ontwerpen*. Groningen/Houten: Noordhoff Uitgevers.

# Bijlage A: Berekening traagheidsmoment

## Bijlage A



ALETTA JACOBS COLLEGE

Scholengemeenschap voor praktijkonderwijs | vmbo | mavo | havo | atheneum | gymnasium

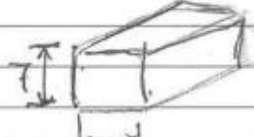
Naam: Rense Veenstra

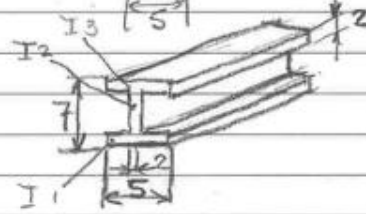
Vak: \_\_\_\_\_

Datum: 13-6-2023 Klas: \_\_\_\_\_

Cijfer:

Voorbeeld berekening traagheidsmoment van massieve balk versus I-balk

\* Massief   $I = \frac{b \cdot h^3}{12}$   
 $= \frac{5 \cdot 7^3}{12}$

\* I-balk   $I_{tot} = \sum (I_i + A_i d_i^2)$   
 $I = 1413 \text{ mm}^4$

Eerst zwaartepunt berekenen:

$$\bar{y} = \frac{\sum y_i \cdot A_i}{\sum A_i} = \frac{(1 \cdot 10) + (5,5 \cdot 10) + (6 \cdot 10)}{10 + 10 + 10} = 4,2 \text{ mm}$$

$$\bar{I}_1 = \frac{5 \cdot 2^3}{12} = 3,34 \quad A_1 = 10 \text{ mm}^2 \quad d_1 = |1 - 4,2| = 3,2$$

$$\bar{I}_2 = \frac{2 \cdot 5^3}{12} = 20,8 \quad A_2 = 10 \text{ mm}^2 \quad d_2 = |4,5 - 4,2| = 0,3$$

$$\bar{I}_3 = \frac{5 \cdot 2^3}{12} = 3,34 \quad A_3 = 10 \text{ mm}^2 \quad d_3 = |6 - 4,2| = 1,8$$

$$I_{tot} = \sum (\bar{I}_i + A_i d_i^2)$$

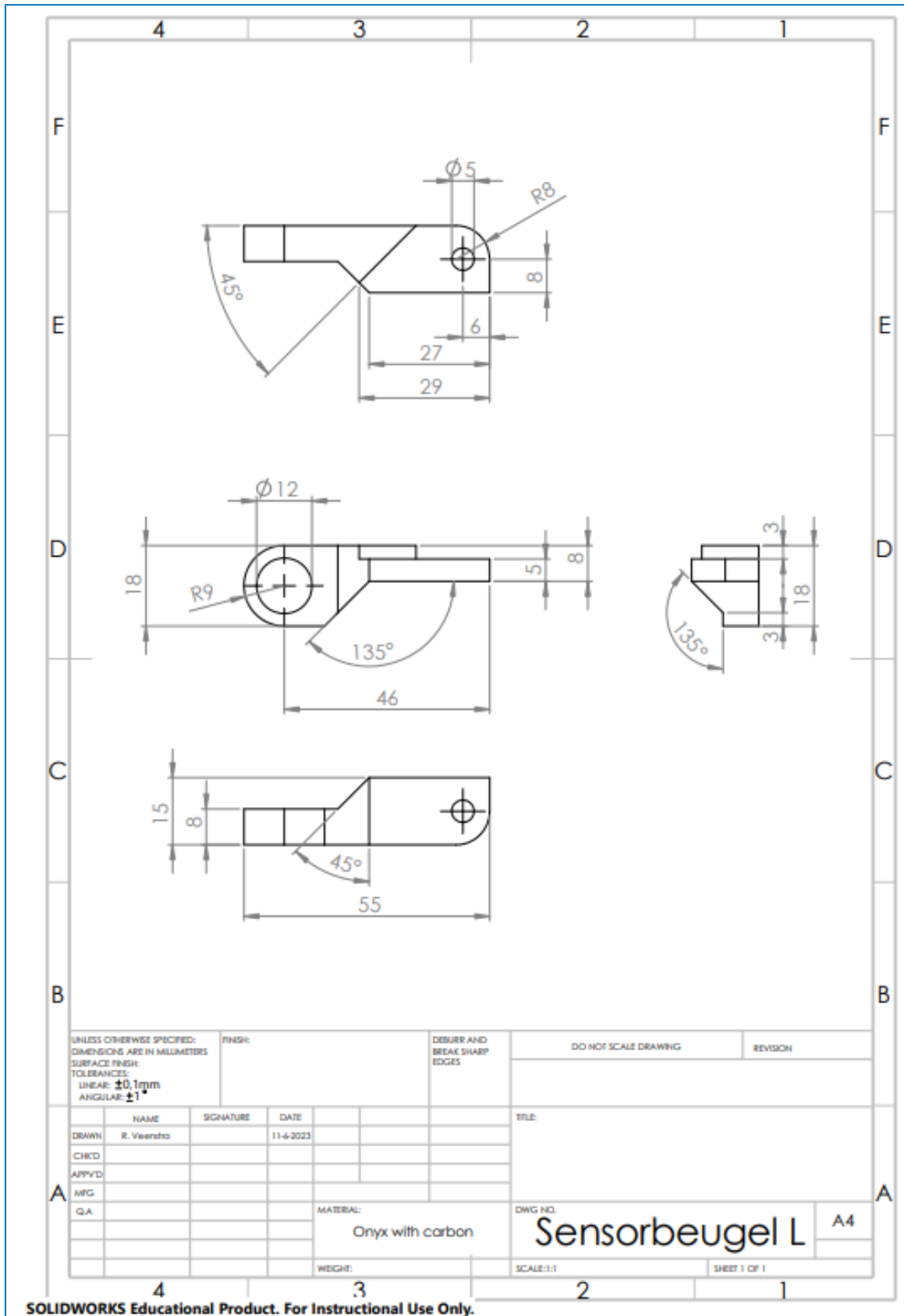
$$= (\bar{I}_1 + A_1 d_1^2) + (\bar{I}_2 + A_2 d_2^2) + (\bar{I}_3 + A_3 d_3^2) =$$

$$= (3,34 + 10 \cdot 3,2^2) + (20,8 + 10 \cdot 0,3^2) + (3,34 + 10 \cdot 1,8^2) =$$

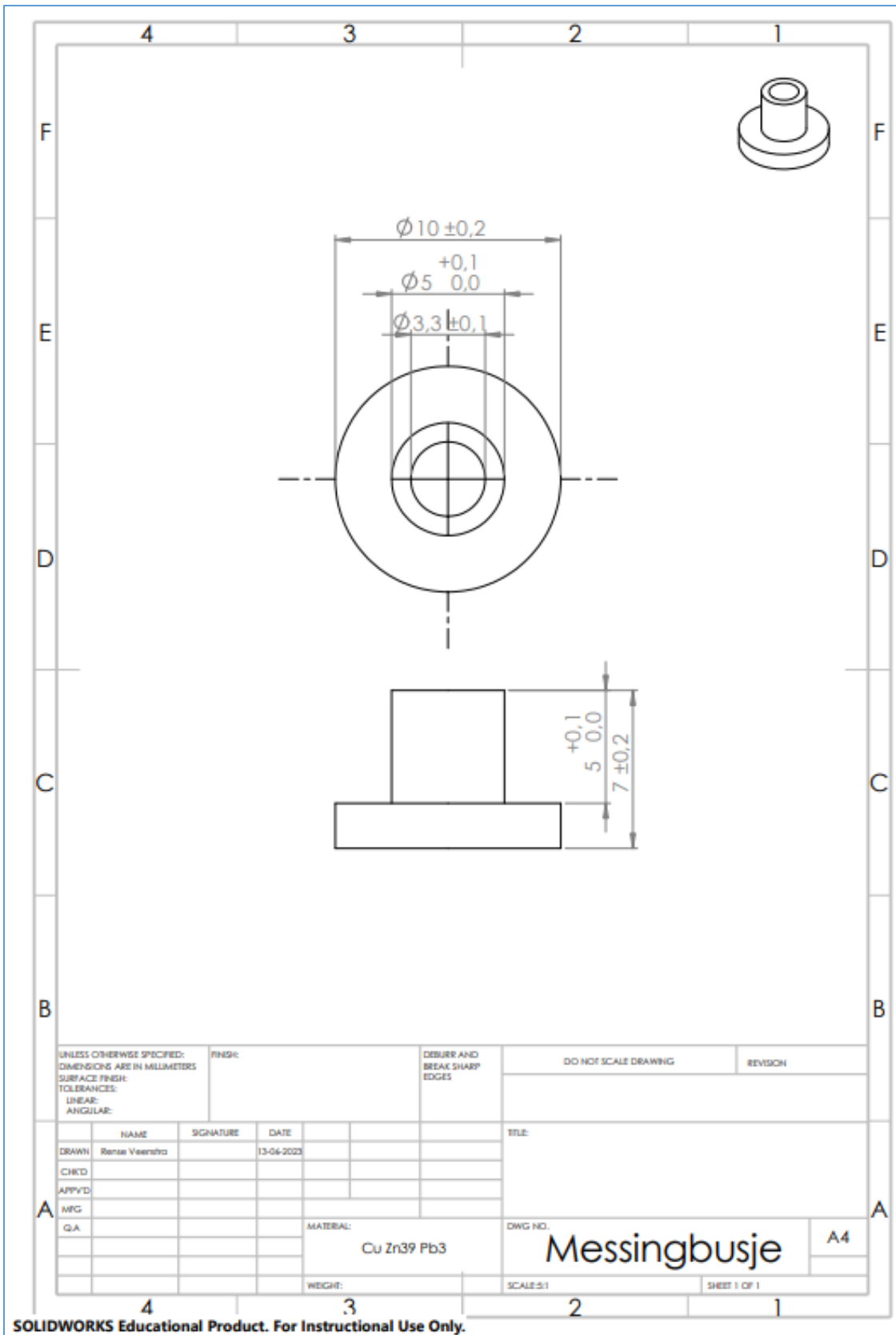
$$= 105,74 + 21,7 + 33,4$$

$$I_{tot} = 160,8 \text{ mm}^4$$

Bijlage B: Enkele 2D-tekeningen



SOLIDWORKS Educational Product. For Instructional Use Only.



SOLIDWORKS Educational Product. For Instructional Use Only.



# Het programmeren en aansluiten van de AFVOERSORTEERDER

Naam leerling: \_\_\_\_\_ Klas: \_\_\_\_\_

- Deze opdracht uit 6 delen waarmee je in totaal 20 punten kunt scoren. Voor elk opdrachtnummer staat hoeveel punten met een goede uitvoering behaald kunnen worden.
- Je krijgt 120 minuten om deze opdracht te maken.
- De opdracht is het deel D van het Centraal Schriftelijk en Praktisch Examen (CSPE) uit 2019. Hiermee kun je al een goede indruk krijgen hoe zo'n examen eruitziet.

## Opdrachtdelen:

1	De afvoersorteerder aansluiten op het EasyRelais en bijgeleverde pneumatiekdelen
2	M.b.v. easysoft op laptop, invoeren van het programma in het EasyRelais.
3	Snelheidsregelventielen instellen.
4	Een waarheidstabel invullen.
5	Schriftelijke vragen beantwoorden.
6	De werking van de afvoersorteerder uitleggen en benoemen van de onderdelen aan de docent. Let erop dat op een nette manier doet (klantvriendelijk zijn).

(College voor Toetsen en Examens, 2019)

Hier zie je afbeeldingen van de afvoersorteerder



(College voor Toetsen en Examens, 2019)

### **Omschrijving van de opdracht:**

Stel je voor dat je een monteur bent die afvoersorteerder gaat plaatsen en aansluiten bij een klant.

De klant is een bedrijf dat bevestigingsmateriaal produceert. Nu komen moertjes die uit de machine komen rechtstreeks in een opvangbak. Het probleem is dat het regelmatig voorkomt dat het productieproces stopgezet moet worden, omdat de (weer) opvangbak overstroomt.

Het bedrijf heeft de afvoersorteerder gekocht bij het bedrijf waar jij als monteur werkzaam bent. Met deze installatie willen ze voorkomen dat de productie iedere keer stopt en daarmee tijd en dus geld besparen.

- Jij bent, als monteur, niet alleen belangrijk om jouw vakmanschap, maar ook een belangrijk contactpersoon.:
  - De afvoersorteerder moet goed geprogrammeerd en aangesloten zijn.
  - Je moet duidelijk aan de klant kunnen uitleggen hoe de installatie werkt.

### **De werking van de afvoersorteerder:**

- Met drukknop S1 schakel je de afvoersorteerder in en met S2 weer uit. M.a.w. de transportband wordt aangedreven door de elektromotor.
- De sensoren S3 en S4 reageren beide op metalen.
- Lamp H1 begint te knipperen als er een bak vol is en deze kan dan worden vervangen door een leeg exemplaar.
- Y1 en Y2 schakelen 5/2-ventiel (V3). Dit ventiel bedient cilinder H2 van de afvalsorteerder.
- De schuif van de afvoersorteerder zorgt voor de sturing van het schroot naar bak 1 of bak 2.
- Snelheidsregelventiel V1 en V2 regelen de snelheid van de schuif.
- Als beide bakken vol zijn, stopt de installatie.

### **Succes met de uitvoering!**

# 1. Aansluiten van de afvoersorteerder

## De afvoersorteerder is uitgevoerd met:

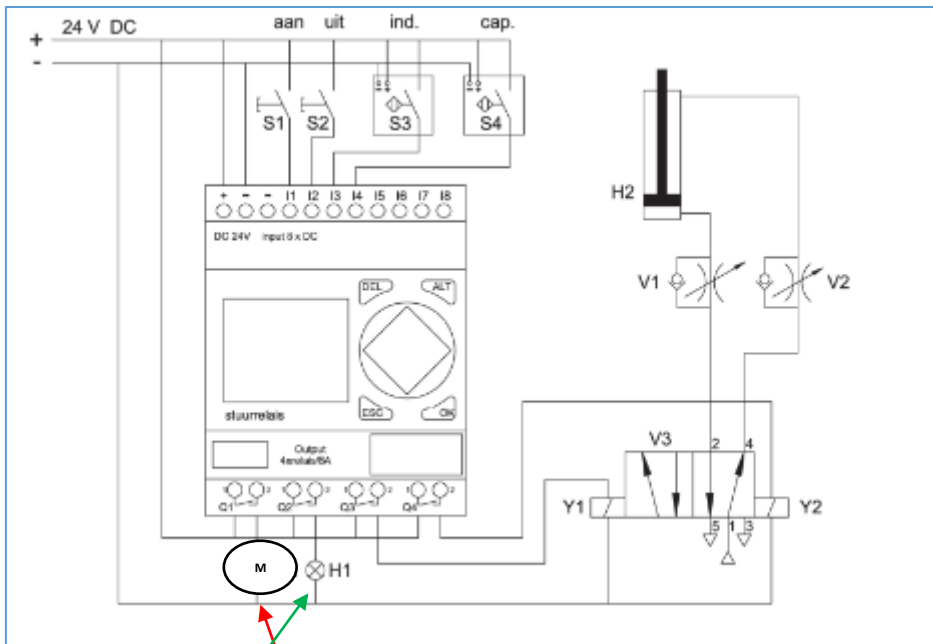
- Pneumatisch bediende schuif (H2),
- waarschuwinglamp (H1),
- transportband aangedreven door een elektromotor (M) en
- 2 inductieve sensoren (S3 en S4).

## Wat extern moet worden aangesloten:

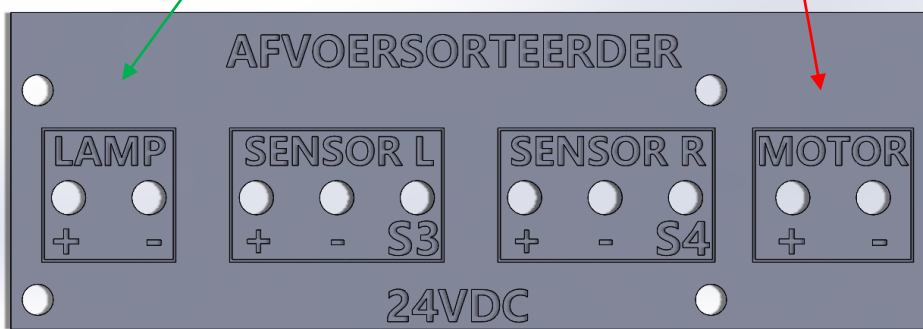
- Knop S1 voor inschakelen aan EasyRelais.
- Knop S2 voor uitschakelen aan EasyRelais.
- De inductieve sensoren van de afvoersorteerder aan het EasyRelais.
- De dubbelwerkende cilinder (H2) pneumatisch aansluiten, via de snelheidsregelventielen (V1 en V2) en het bi-stabiele elektrisch bediende 5/2 stuurventiel (V3). Deze is op zijn beurt weer aangesloten op het EasyRelais.
- Lamp (H1) van afvoersorteerder aansluiten op het EasyRelais.
- Motor (M) van afvoersorteerder aansluiten op het EasyRelais.

## De uitvoering:

- Sluit de onderdelen aan volgens het elektro-pneumatisch schema op de volgende bladzijde.
- Vraag de docent om de schakeling te controleren.
- Als de schakeling niet juist is opgebouwd, mag je één keer proberen fouten te herstellen. Je kunt dan nog een deel van de punten behalen.
- Vraag de docent daarna om de schakeling en de werking opnieuw te controleren.
- Als de schakeling nu nog niet juist is opgebouwd, zal de docent dit voor je doen.
- Daarna kun je verder met de volgende opdracht: invoeren programma in EasyRelais.



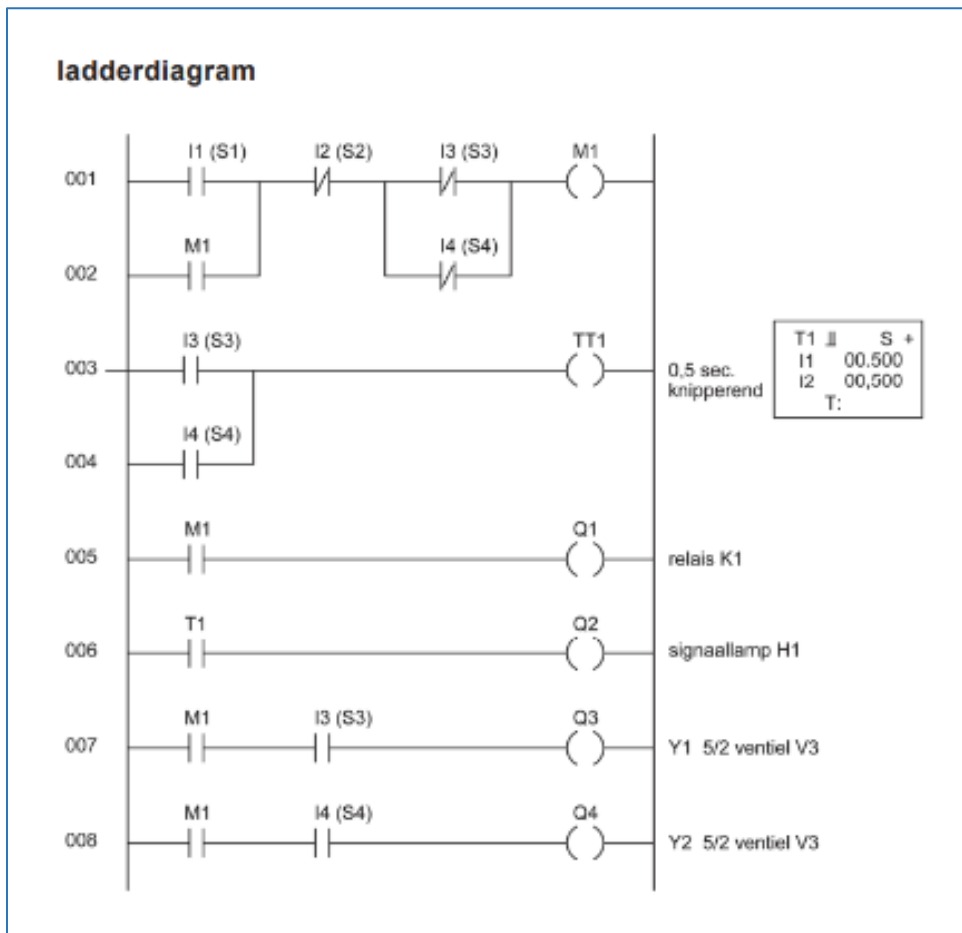
(College voor Toetsen en Examens, 2019)



(College voor Toetsen en Examens, 2019)

## 2. Programmeren van het EasyRelais

Je gaat nu het bijgaande programma/ladderdiagram m.b.v. easysoft maken en wegschrijven in het EasyRelais.



(College voor Toetsen en Examens, 2019)

### De uitvoering:

- Lees eerst de bladzijden 47 t/m 54 door van **TRAININGSHANDBOEK EasySoft 7**
  - Voor het programmeren van de timer lees je bijlage B van deze opdracht door.
- Programmeer het stuurrelais volgens het bovenstaande ladderdiagram
- Vraag de docent om de werking van het programma te controleren.
- Als het EasyRelais niet juist is geprogrammeerd, mag je één keer proberen fouten te herstellen. Je kunt dan nog een deel van de punten behalen.
- Vraag de docent daarna om het programma en de werking opnieuw te controleren.
- Als het EasyRelais nog niet juist is geprogrammeerd, zal de docent dit voor je doen.
- Daarna ga je verder met het instellen van de snelheidsregelventielen.

(College voor Toetsen en Examens, 2019)

### 3. Instellen van de snelheidsregelventielen

De snelheidsregelventielen moeten juist worden ingesteld.

#### De uitvoering:

- Stel de snelheidsregelventielen zó in dat de cilinder vertraagd in- en uitgaat.
- Zorg ervoor dat de snelheid van de uitgaande slag ongeveer even groot is als de snelheid van de ingaande slag.
- Als je klaar bent vraag je de docent om de ingestelde snelheidsregelventielen te controleren.

## 4. Invullen van het waarheidstabel

Vul de waarheidstabel voor de vul-installatie in.

### Voordat je begint

- Bekijk nog eens het elektro-pneumatisch schema, het ladderdiagram en de tekst over de werking van de vul-installatie.
- Bekijk hieronder wanneer je een 0 en een 1 moet invullen. Je gebruikt de schakeling van opdracht 1 voor het invullen van de tabel.

De drukknop is bediend of de sensor is actief.	1
De drukknop is onbediend of de sensor is in rust.	0
De actuator is actief / de cilinder is uit.	1
De actuator is niet actief / de cilinder is in.	0

### Uitvoering

- Vul de waarheidstabel in als je de volgende bediening uitvoert:
  - stap 0: deze ruststand is al ingevuld
  - stap 1: je houdt S1 ingedrukt (bediend)
  - stap 2: je laat S1 los (onbediend)
  - stap 3: je activeert S3 (met een metalen plaatje)
  - stap 4: je haalt het plaatje bij S3 weer weg
  - stap 5: je activeert S4 (met een metalen plaatje)
  - stap 6: je haalt het plaatje bij S4 weer weg
  - stap 7: je activeert S3 en S4 met een metalen plaatje
- Vul op elk stippelijntje onder actuatoren een 0 of een 1 in.

### waarheidstabel

	sensoren				actuatoren		
	S1	S2	S3	S4	K1	H1	H2
stap 0 (ruststand)	0	0	0	0	0	0	0
stap 1	1	0	0	0	.....	.....	.....
stap 2	0	0	0	0	.....	.....	.....
stap 3	0	0	1	0	.....	.....	.....
stap 4	0	0	0	0	.....	.....	.....
stap 5	0	0	0	1	.....	.....	.....
stap 6	0	0	0	0	.....	.....	.....
stap 7	0	0	1	1	.....	.....	.....

## 5. Schriftelijke vragen

Beantwoord de vragen over het elektro-pneumatisch schema en het programma van de vul-installatie.

vraag 1

Hoe heet het contact van drukknop S1?

- maakcontact
- verbreekcontact
- wisselcontact
- overneemcontact

vraag 2

Welke functie heeft contact M1 op regel 002?

- verbreekcontact
- wisselcontact
- overneemcontact
- vergrendelcontact

vraag 3

Op welke spanning moet het stuurrelais worden aangesloten?

..... volt

vraag 4

Moet het stuurrelais worden aangesloten op een wisselspanning of op een gelijkspanning?

- wisselspanning
- gelijkspanning

vraag 5

Wanneer gaat signaallamp H1 knipperen?

.....  
.....

vraag 6

Wat gebeurt er als beide schrootbakken vol zijn?

.....



## 6. De werking van afvoersorteerder uitleggen aan de docent

Leg in een gesprek de werking van de elektro-pneumatische schakeling uit.

### **Voordat je begint**

Bekijk nog een keer het elektro-pneumatisch schema en de werking van de schakeling.

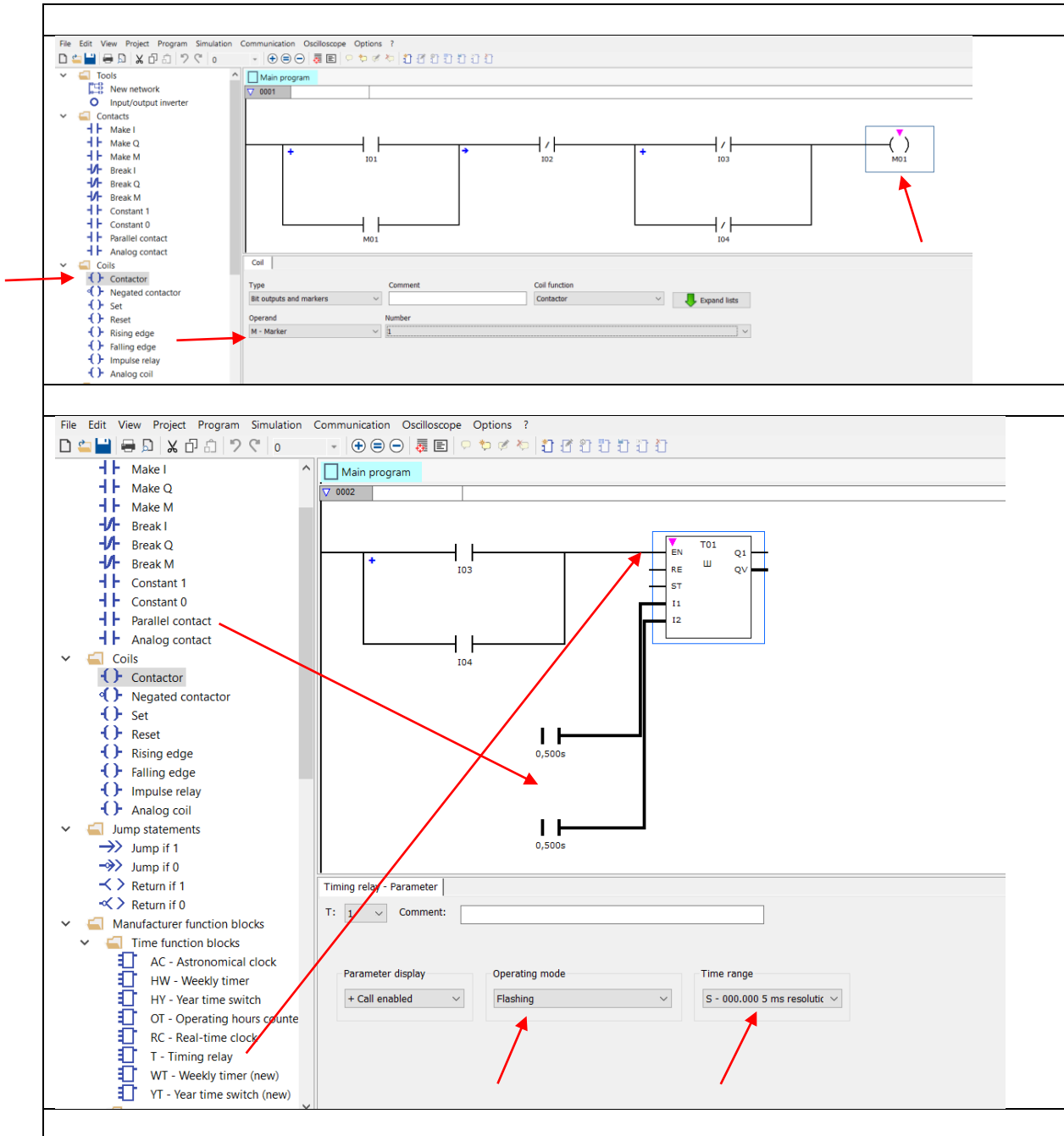
### **Uitvoering**

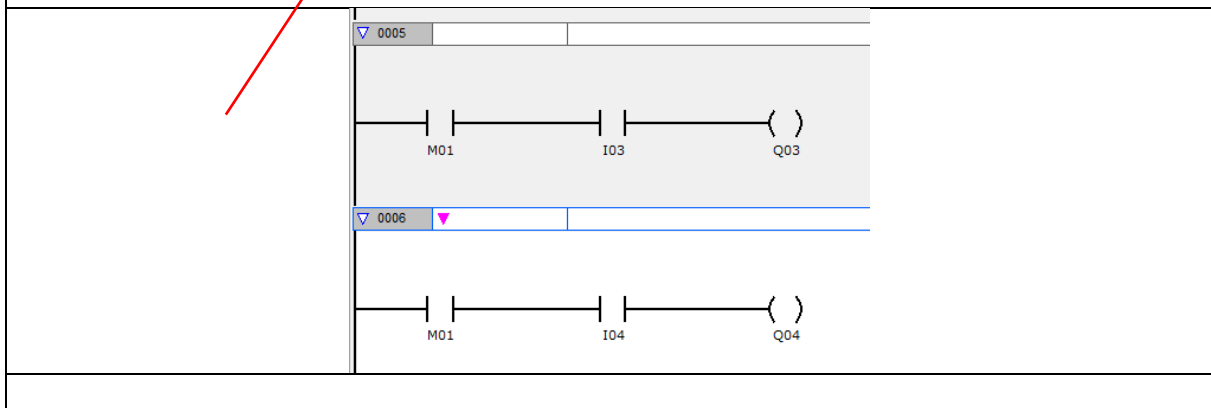
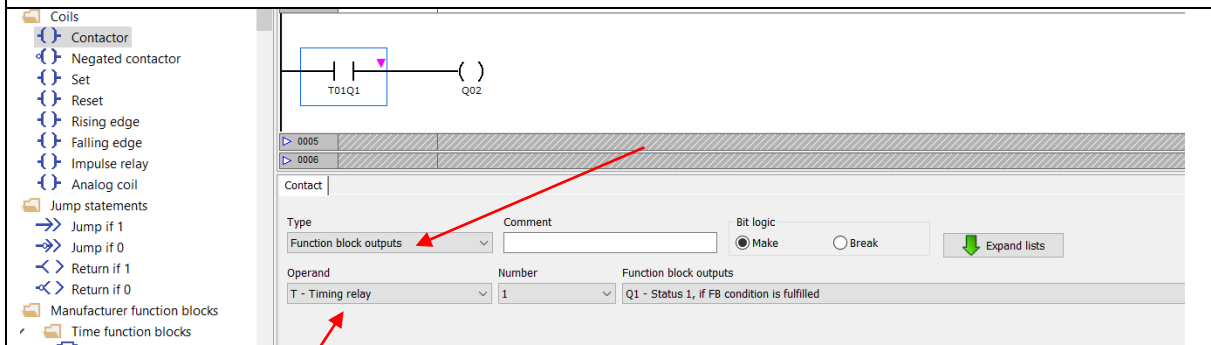
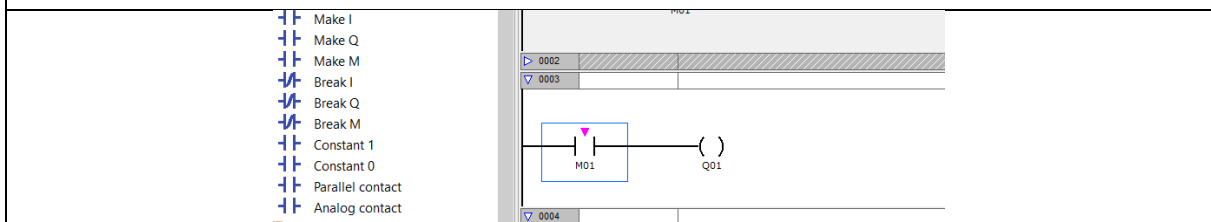
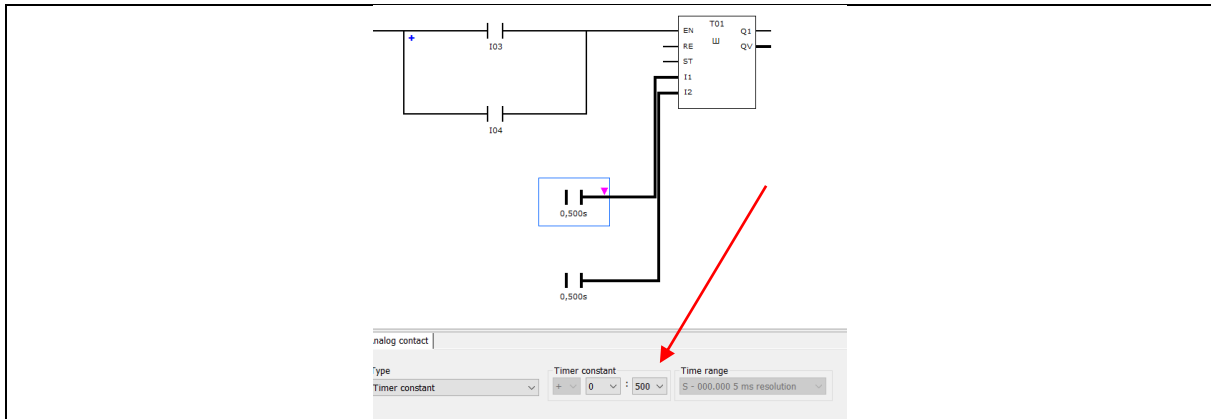
- Voer een gesprek met de examiner over de elektro-pneumatische schakeling.
- Tijdens het gesprek mag je alleen het schema en het ladderdiagram van **Bladzijden 4 en 5 gebruiken.**
- Leg duidelijk aan de examiner uit hoe de vul-installatie werkt. Leg ook het programma uit.
- Benoem bij je uitleg de onderdelen van de schakeling.

Let op: je wordt ook beoordeeld op gespreksvaardigheden. Wees klantvriendelijk en spreek duidelijk.

(College voor Toetsen en Examens, 2019)

**Bijlage A: Programmeren Afvoersorteerder in EasySoft (nakijkmodel)**





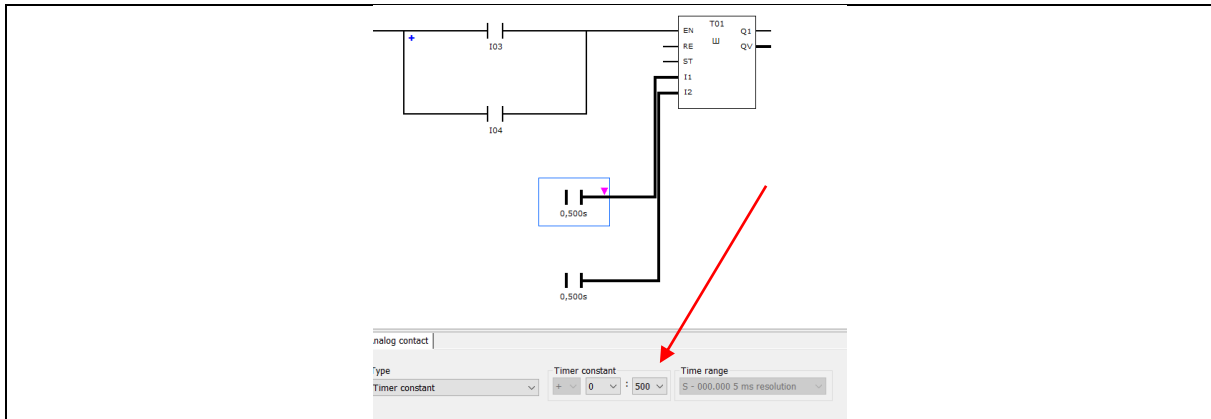
### Bijlage B: Programmeren Timer

Lees eerst de bladzijden 47 t/m 54 door van **TRAININGSHANDBOEK EasySoft 7**

- 1<sup>e</sup> Timing relay plaatsen
- 2<sup>e</sup> Operating mode op "Flashing"
- 3<sup>e</sup> Time range op "5 ms resolution"
- 4<sup>e</sup> De analoge contacten plaatsen naar I1 en I2

The screenshot displays the EasySoft 7 software interface. On the left is a component library with categories like Coils, Jump statements, and Time function blocks. The 'Timing relay' (T) is selected. The main workspace shows a ladder logic diagram with two normally open contacts labeled 103 and 104 in series, connected to the EN input of a timing relay block labeled T01. The relay has outputs Q1 and QV. Two pulse generators, each set to 0,500s, are connected to the I1 and I2 inputs of the relay. Below the diagram, the 'Timing relay - Parameter' dialog is open, showing 'Operating mode' set to 'Flashing' and 'Time range' set to 'S - 000.000 5 ms resolutic'. Red arrows point from the text instructions to the corresponding elements in the software: from 'Timing relay' in the library to the T01 block; from 'Operating mode' to the 'Flashing' dropdown; from 'Time range' to the '5 ms resolution' dropdown; and from 'analoge contacten' to the I1 and I2 inputs.

- 5<sup>e</sup> Bij beide contacten de tijd ingeven



- 6e Plaatsen maakcontact "Make I"
- 7e Type op "Function block outputs"
- 8e Operand op "Timing relay"

The screenshot shows the software interface for creating a PLC program. On the left is a library of components:
 

- Input/output inverter
- Contacts: Make I, Make Q, Make M, Break I, Break Q, Break M, Constant 1, Constant 0, Parallel contact, Analog contact
- Coils: Contactor, Negated contactor, Set, Reset, Rising edge, Falling edge, Impulse relay, Analog coil
- Jump statements: Jump if 1, Jump if 0, Return if 1, Return if 0
- Manufacturer function blocks

 On the right, a ladder logic diagram is shown with three rungs:
 

- Rung 0004: A contact labeled T01Q1 connected to a coil Q02.
- Rung 0005: Two normally open contacts M01 and I03 connected to a coil Q03.
- Rung 0006: Two normally open contacts M01 and I04 connected to a coil Q04.

 Below the diagram is the configuration window for the selected contact. It shows:
 

- Type: Function block outputs
- Operand: T - Timing relay
- Number: 1
- Function block outputs: Q1 - Status 1, if FB condition is fulfilled


 Red arrows indicate the selection of 'Make I' from the library, 'Function block outputs' for the Type, and 'T - Timing relay' for the Operand.

## Bijlage F: Screenshot uit feedback werkplekbeleider

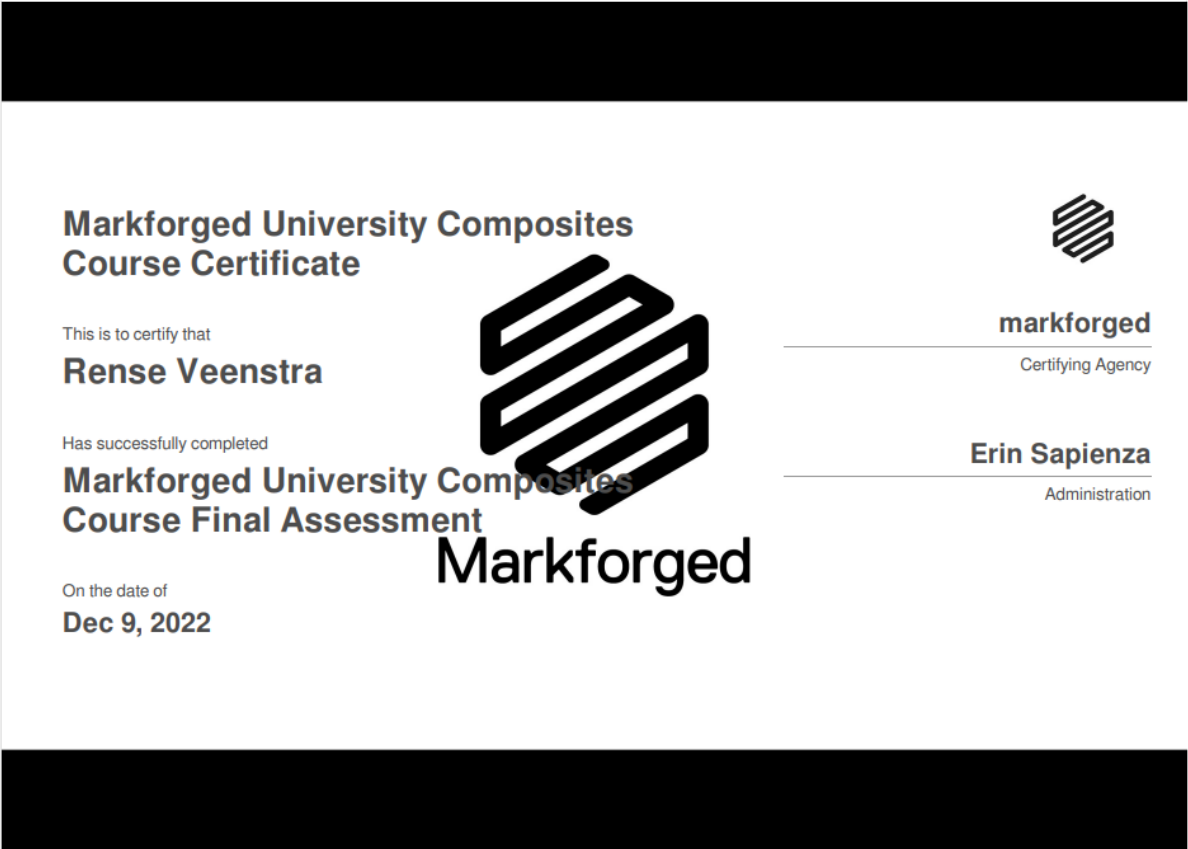
<b>Wat ziet u als sterke kwaliteiten van de deelnemer?</b>	
<b>Kwaliteit</b>	<b>Toelichting</b>
Betrouwbaar	Rense is eerlijk en integer en komt na wat afgesproken is.
Gedrevenheid	Rense is gepassioneerd, enthousiast en gemotiveerd.
Geduldig	Rense is iemand die onderwerpen meerdere malen uit kan leggen zonder dat het hem irriteert.
Betrokkenheid	Rense is zeer betrokken in het team, wil graag wat voor een ander doen en probeert anderen van dienst te zijn, dit wordt wel bevestigd door de relatie die Rense met de leerlingen heeft, deze is meer dan goed te noemen.

<b>Op welke punten is nog ontwikkeling gewenst?</b>	
<b>Kwaliteit</b>	<b>Toelichting</b>
Perfectionistisch	Rense heeft wel eens de neiging om dingen te goed te willen doen, het oog voor detail is groot maar dit kan irritaties geven.
Gevoelsmens	Hoewel dit tevens een kracht is van Rense kan dit ook een valkuil zijn, denk aan een leerling die zijn dag niet heeft en er dat moment weinig aan te doen is je het persoonlijk aantrekt.
Bondigheid	Rense mag soms iets compacter zijn in zijn woorden.

Pagina 11



# PLAN VAN AANPAK

## PROJECT AFVOERSORTEERDER

Naam student	Rense Veenstra	rense.veenstra@windesheim.nl
Datum	7 Maart 2024	
Plaats	Hoogezand	
Opdrachtgever	Dr. Aletta Jacobs College	
Professionaliseringstraject PIE	Integratief leermiddel	
Studentnummer	1073458	
Begeleidende docent	Henk Spaan	h.spaan@windesheim.nl
Begeleidende docent	Michel Greeven	m.greven@windesheim.nl



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## 1. Achtergronden

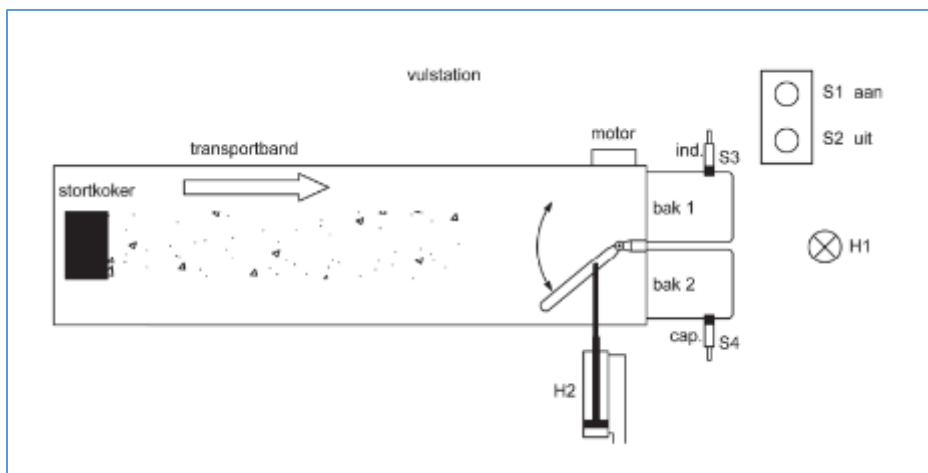
Ter voltooiing van mijn opleiding “Professionaliseringstraject PIE” moet er een integratieve opdracht worden uitgevoerd, waarbij minimaal 2 vakgebieden van het profiel PIE (Produceren, Installeren & Energie) in terug moeten komen. Daar het voor buitenstaanders m.i. de profielnaam niet altijd duidelijk is hebben we het in grote lijnen over:

- **Produceren:** Metaaltechnieken, zoals verspaning en plaatbewerking.
- **Installeren:** Drinkwater, sanitair en afvoer.
- **Energie:** Elektro- besturingstechniek.

### 1.1. Probleemstelling m.b.t. de huidige PTA-opdracht; Onderdeel D (blauw), CSPE 2019

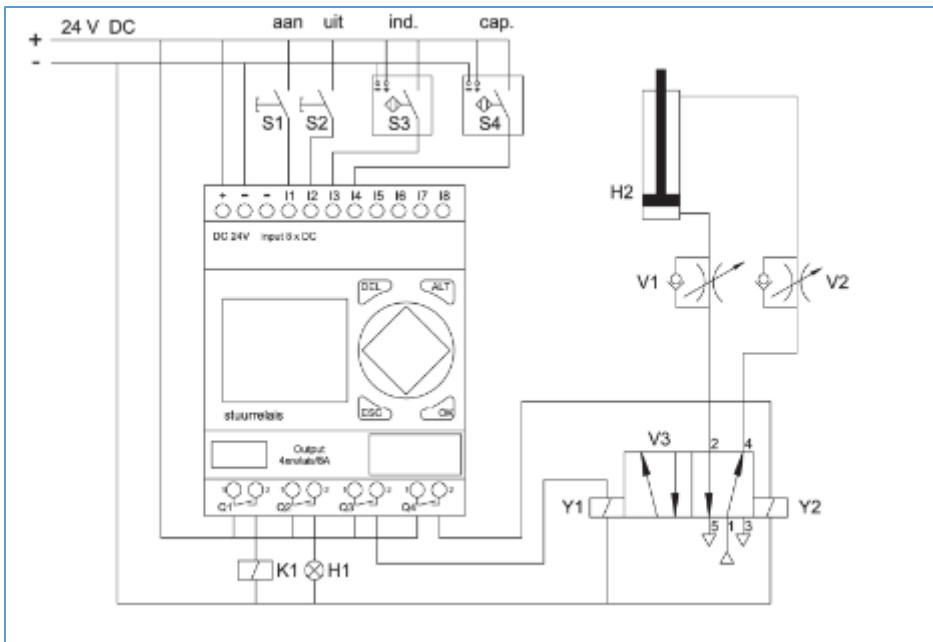
De werkelijke (hetzij onbewuste) opdrachtgevers zijn onze leerlingen. Ze geven dikwijls aan geen beeld te hebben waarom en hoe besturingstechniek, in het bedrijfsleven, wordt toegepast. Na een aantal formatieve opdrachten, zoals elektropneumatiek, programmeren en aansluiten van de EasyRelais, moet de leerlingen de summatieve PTA-opdracht is de zogenaamde “Afvalsorteerder” voltooien. Dit is een opdracht waarvoor rechtstreeks het blauwe onderdeel D van het CSPE 2019 wordt gebruikt. [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

Ondanks afbeelding in figuur 3 en de opdrachtomschrijving is het voor de leerlingen lastig zich een voorstelling te maken hoe zo iets er in het echt zou kunnen uitzien en werken.

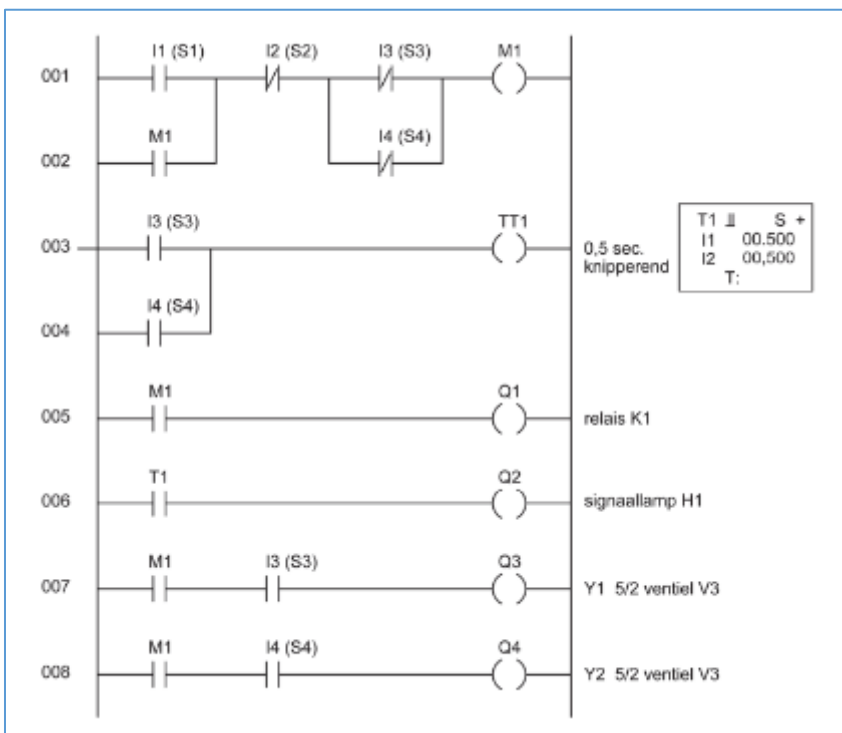


Figuur 3: De afvalsorteerder (College voor Toetsen en Examen, 2019) (bron CSPE 2019, onderdeel D Blauw)

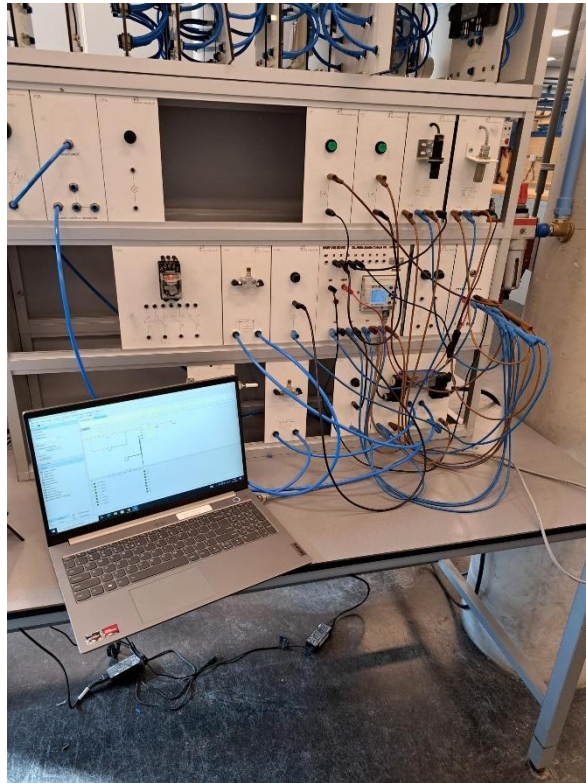
Het programmeren wordt vaak als lastig ervaren en de toepassingen in het bedrijfsleven, zijn voor hen veelal abstract. Met een apparaat, die ook daadwerkelijk doet, wat in de opdracht staat omschreven, zal het nut duidelijk worden en de materie beter bekliven.



Figuur 4: Elektro pneumatisch schema voor de afvalsorteerder (College voor Toetsen en Examens, 2019) (bron CSPE 2019, onderdeel D Blauw)



Figuur 5: Ladderdiagram voor de afvalsorteerder (College voor Toetsen en Examens, 2019) (bron CSPE 2019, onderdeel D Blauw)



Figuur 6: Zoals de opdracht nu in praktijk wordt uitgevoerd

Hierbij waren, voor mij, de 7 Hulpvragen (6 W's) van Verhoeven een hulpvolle methode (Verhoeven, 2018):

<b>Wie</b>	Leerling.
<b>Wat</b>	Door abstractie onduidelijkheid over het nut bij de leerling.
<b>Waar</b>	Op de werkplekken/experimenteerborden waar de opdrachten worden uitgevoerd.
<b>Wanneer</b>	Bij het uitvoeren van de summatieve opdracht "Afvoersorteerder".
<b>Waarom</b>	Een aangesloten en geprogrammeerde EasyRelais met alleen actuatoren als schakelrelais, een signaal lamp en dubbelwerkende persluchtcilinder geeft geen duidelijk genoeg beeld over waar het voor dient. Ook de toepassing van de ingangssignalen m.b.v. capacitieve en/of inductieve sensoren spreken niet tot de verbeelding. Dus nodig is een werkend apparaat waarmee gedemonstreerd wordt, wat er na gebeurt als het eerst bakje volloopt, enz. ....
<b>Waardoor</b>	Leerlingen hebben (nog) geen excursie gehad bij een procesfabriek waar automatisering wordt toegepast. Naast technisch ook geen (volledig) beeld van economisch voordeel (humane arbeid versus automatisering/robotisering).

## 2. Projectresultaten

Waarom het project wordt geïnitieerd:

- Het bewust maken van het nut en doel van besturingstechniek bij onze PIE-leerlingen, die een aantal items gaan maken (3D-printen en metaaltechniek) en programmeren.

Daarom is gekozen voor het ontwikkelen en vervaardigen van een apparaat die afgeleid is van figuur 3. Wel willen we meer de nadruk leggen dat het apparaat gebruikt wordt om te waarborgen dat productieprocessen gecontinueerd worden, van bijvoorbeeld afvoer en collecteren van M4-moertjes. De naam zal op termijn dan ook gewijzigd worden, van "Afvalsorteerder", in "Afvoersorteerder".

### 2.1. Projectresultaat schoolopdracht Afvoersorteerder

SMART:

- **Specifiek:** In de Afvoersorteerder moeten 2 magazijnbakken geplaatst kunnen worden en er moet gesignaleerd worden wanneer de eerste bak vol is bouwblokjes. Vervolgens moet de installatie de afvoerstream wijzigen naar de tweede bak. De installatie moet stoppen als de tweede bak ook vol is. Het programma voor de EasyRelaisbesturing wordt in de opdracht aangeleverd. De leerling moet een programma kunnen invoeren, niet te ontwerpen.
  - Het betreft hier een summatieve PTA-opdracht van de verplichte module 3 Besturen en Automatiseren, waar de leerlingen dus een cijfer mee scoren.
  - De opdracht is voor KB-niveau PIE. Deze is nu de opdracht "Afvalscheider" die in het volgende cohort "Afvoerafvoerder"
- **Meetbaar:** De leerling zal kunnen uitleggen waar de productie-afvoerder voor dient.
- **Aanwijsbaar/ Acceptabel:** Rense Veenstra is verantwoordelijk voor het eindresultaat, d.w.z. een afvoersorteerder ontwikkelen en fabriceren.
- **Realistisch:** De afvoersorteerder kan gemaakt worden met:
  - Catalogus inkoopdelen,
  - Machinepark beschikbaar en geschikt om de onderdelen te kunnen maken.
  - Een professionele 3D-printer is beschikbaar, waarmee met composiet versterkte materialen kan worden geprint, zoals carbon, kevlar en glasvezel.
- **Tijdgebonden:** De Productie-afvoerder moet voor 29 juni 2024 gereed zijn.

## 2.2. Programma van eisen

Functioneel	Fabricage	Programma van eisen	Vaste eis	Variabele eis	Wens	N.v.t.
X		De installatie moet geschikt zijn voor het uitvoeren van onderdeel D van CSPE 2019. Deze is opgenomen in het PTA van module Besturen en Automatiseren.	X			
	X	Idem.		X		
		<ul style="list-style-type: none"> <li>De opdracht moet de delen P/PIE/3.1 van Besturen en Automatiseren afdekken, op KB-niveau. Met de productieafvoerder moeten de volgende onderwijscomponenten uitgevoerd kunnen worden:</li> </ul>				
X		9. Een pneumatische schakeling opbouwen.	X			
X		10. Een programmeerbare EasyRelais aansluiten en een programma invoeren.	X			
X		11. Sensoren en actuatoren kiezen en aansluiten.	X			
X		12. Een regelsysteem opbouwen, aansluiten en testen.	X			
		13. Een domotica-installatie opbouwen, aansluiten en testen.				X
X		14. Storingen en fouten zoeken en verhelpen in de opgebouwde schakeling.		X		
		15. Metingen uitvoeren aan een besturingsinstallatie.				X
		16. een verslag maken en de resultaten presenteren			X	
		<ul style="list-style-type: none"> <li>De opdracht moet de delen P/PIE/3.3 van Besturen en Automatiseren afdekken, op KB-niveau. Met de productieafvoerder moeten de volgende onderwijscomponenten uitgevoerd kunnen worden:</li> </ul>				
X		6. Besturingscomponenten plaatsen aan de hand van een opstellingstekening.		X		
X		7. De besturingscomponenten bedraden en aansluiten aan de hand van een bedradingsstekening.	X			
X	X	8. Een programma invoeren in een programmeerbaar relais.	X			
X		9. De automatische besturing testen.		X		
		10. De automatische besturing demonstreren en presenteren.	X			
X		De opdracht moet in 3 lesuren van 45 minuten gerealiseerd kunnen worden.	X			
X		100% van de productiedelen (moertjes) moeten tijdens transport aankomen.		X		
X		Afvoerproces mag niet stoppen moet continue doorgaan. (Door bijvoorbeeld productieafvoer automatisch in 2 stromen te kunnen leiden).	X			
X		Operator moet tijdig gewaarschuwd worden als het proces dreigt te stoppen.	X			
X		Als de operator verzaakt om tijdig in te grijpen, moet het proces alsnog stoppen.	X			
	X	Snelheid afvoertransport moet 50mm/s zijn.		X		
X		Veiligheid: afscherming van aandrijving.	X			
	X	Afmetingen afvoersorteerder: L x B x H = 300 x 100 x 100.		X		
	X	Gewicht ≤ 5kg.		X		
	X	Te maken met cataloguskoopdelen, 3D-printer, plaatdelen 2mm en inkoopdelen Brink Techniek BV.		X		
	X	De maakkosten mogen niet hoger dan €500,-.		X		
	X	De afvoersorteerder moet gemaakt kunnen worden in 3 maanden.		X		
	X	Bij een val van 1,5m geen ontzetschade aan de ophanging.		X		
X		Weinig onderhoud.		X		
	X	Defecte geraakte onderdelen moeten binnen 24 uren te vervangen zijn.		X		
X		Werking betrouwbaar.		X		
	X	Complexiteit onderdelen laag.		X		
	X	Zo weinig mogelijk onderdelen.		X		

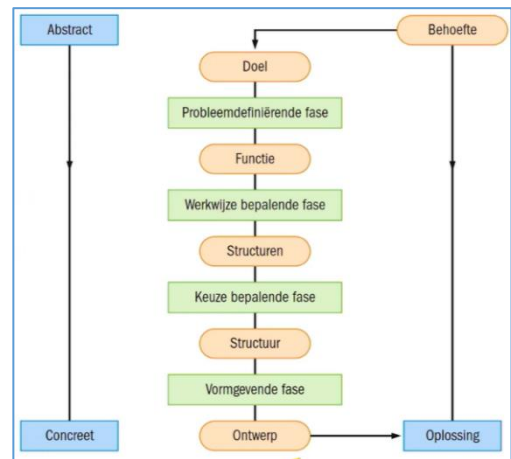
Naar (Zeiler, 2014)

### 3. Projectactiviteiten

- Het maken en inleveren van dit PVA
  - GO afwachten, bij NOGO direct corrigeren,
- Het schrijven van het dossier en morfologische kaart.
  - Keuze van de morfologie.
- Ontwerpen van de afvoersorteerder.
- Inkopen van onderdelen.
- Het maken van de metaal- en 3D geprinte onderdelen.
- Het assembleren van de Afvoersorteerder.
- Testen van de afvoersorteerder > PDCA (Plan Do Check Action)
- Aanpassen van de afvoersorteerder.

Ik ga de stappen uit het boek Basisboek Ontwerpen van Wim Zeiler gevolgen om zo mijn ontwerp dossier te maken. Daarbij

is het proces ingedeeld in de volgende fases: A - probleem definiërende fase. B - werkwijze bepalende fase. C - keuzebepalende fase. D - vormgevende fase (Zeiler, 2014).



Figuur 7: Ontwerpfasering volgens Zeiler (Zeiler, 2014)

### 4. Projectgrenzen

Zoals al omschreven in §2.2. blijft de afvoersorteerder beperkt tot de functies om hiermee de summatieve opdracht te kunnen realiseren, waarmee syllabusdelen P/PIE/3.1 en P/PIE/3.3 mee worden voldaan. Hieruit vloeien alleen de strikt noodzakelijke fabricage-eisen van de afvoersorteerder.

### 5. Tussenresultaten

- PVA klaar in week 10
- Dossier klaar in week 23
- Product klaar in week 22
- Eindassessment week 26

### 6. Kwaliteit

De afvoersorteerder moet hufter proof gemaakt worden. De ophanging moet dermate stijf geconstrueerd worden dat een valhoogte van 1.5 m geen schade geen ontzetschade ontstaat.

### 7. Projectorganisatie

Naam	functie	Projectactiviteiten.
Rense Veenstra	Docent PIE	Afstuderend d.m.v. dit project en alle verder genoemde activiteiten.
Rolf Ahlers	Technisch onderwijs assistent	Voor advies en assisteren bij fabriceren en assembleren.
Chris Toren	Docent PIE	Aanpassen van summatieve opdracht afvoersorteerder
Henk Spaan	Docentenopleider, Windesheim	Begeleiding
Monika Smit	Teamleider vmbo dr. AJC	Facilitering uren

## 8. Strokenplanning

Voor het maken van de strokenplanning heb ik gebruik gemaakt het model uit het boek "Projectmanagement" van Roel Grit

Project:		Datum opgesteld: 3 maart 2023										Opgesteld door:										Naam: Rense Veenstra					
Taak		7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Tot
<b>Vorbereiding</b>																											
PVA		8	2	7																							17
Afspraak Henk Spaan			4																								4
<b>Uitvoering</b>																											
Afspraak maken eind assessment						1																					1
Morfologische kaart					8																						8
Schrijven dossier							1	1	1	1	1	1	1	1	1	1	4										14
Ontwerpen van de afvoersorteerder						7	7	7																			21
Inkoopdelen				1					1	1																	3
Metaalonderdelen									7	7	7																21
3D printen											1																1
Assembleren												8	8														16
Testen														8													8
Iteratie (PDCA)															8												8
Aanpassen summatieve opdracht afvoersorteerder																8	4										12
Uitloop																		8	8								16
<b>Afhandeling</b>																											
Eindassessment																					8						8
Zomervakantie 24 juli dr. AJC																									V	V	
Onderwijsluwe weken Windesheim																									V	V	
<b>Totaal</b>			8	6	8	8	8	8	8	9	9	9	9	9	9	9	9	8	8	8	8						158

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Hoort bij het boek

*Projectmanagement*

Noordhoff Uitgevers  
bv

<http://www.roelgrit.nl/>

Gebruikte layout van (Grit, 2015)



## 9. Kosten en baten

De kosten zijn de investering van de manuren, inkoopdelen en materiaalkosten.

- De baten voor een fictief bedrijf zou een ferme kostenreductie zijn t.g.v. uitbannen van verspilling tijd door productiestagnatie. Hier wordt niet verder op ingegaan.
- Aangaande baten voor de onderwijscomponent zal de leerling, uit het voorgaande, het belang zien van automatiseren. Daarnaast zal leerlingen, m.b.v. de summatieve PTA-opdracht (als voorbeeld dienende) een beter beeld krijgen hoe automatisering toegaat in productie- en procesbedrijven. Een bezoek aan een dergelijk bedrijf kan/zal hiervan een deel uitmaken. Het zal een bijdrage leveren aan LOB (Loopbaanoriëntatie).
  - Zoals al aangehaald in §2.2 zijn de kosten geraamd op €500,-

## 10. Risico's

De reële risico's die genoemd moeten worden, worden gevormd door een ruim takenpakket, met nogal wat onverwachte wendingen.

- Ik ben mentor van een BB-klas, waar veel problemen spelen en waarmee veel (onverwachte/incidentele) aandacht wordt gevestigd.
- Naast PIE-docent ben Sectievoorzitter van PIE.
- Organisator van verschillende projecten, ter promotie van Techniek.
- 8 Uren (op de dinsdag) ben ik medewerker van het netwerkbureau PIT (Passie In Techniek), dat vanuit STO (Sterk Techniek Onderwijs). Het betreft hier samenwerking tussen de scholen Winkler Prins, te Veendam en dr. Aletta Jacobs College, te Hoogezand.
  - Het risico hierin is dat de programmamanager in december 2022 gestopt is en men met vragen bij mij terecht komen. Ook word ik door programmamanagers van andere STO-regio's beschouwd als de (tijdelijke) opvolger. Vergaderingen worden tijdens lessen gepland, die ik dan weer moet cancelen. Er wordt gezegd dat ik dat zelf maar moet inschatten welke vergadering informatief belangrijk zijn, voor beide partijen. Ik heb de Directie al gevraagd hoe de opvolging van onze programmamanager geregeld wordt, maar we zijn inmiddels 2 maand verder en er is (zo ver ik weet) nog geen oplossing.

## Verwijzingen PVA

College voor Toetsen en Examens. (2019). *Produceren, installeren en energie vmbo kb*. Opgehaald van Examenblad.nl: [https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp\\_1300\\_b\\_19\\_1\\_d\\_o.pdf](https://www.examenblad.nl/system/files/2019/profielen-vmbo/kp_1300_b_19_1_d_o.pdf)

Grit, R. (2015). *Projectmanagement*. Groningen/Houten, The Netherlands: Noordhoff Uitgevers bv.

Verhoeven, N. (2018). *Wat is onderzoek?* Amsterdam: Boom uitgevers Amsterdam.

Zeiler, W. (2014). *Basisboek Ontwerpen*. Groningen/Houten: Noordhoff Uitgevers.

# Bijlage I: Samenvatting: Markforged University Composites Training Program

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## Introduction

### Markforged University Composites Training Program

The Composites Training Program is designed to help you build and develop the skills necessary to take advantage of Markforged composite-reinforced 3D printing technology to accelerate and simplify your everyday engineering or technical work. In this three-part training program, consisting of Core, Essential, and Advanced Composites, your instructors will guide you as you explore the fundamental operating principles of Markforged composite 3D printing, develop your skills in Design for Additive Manufacturing (DfAM) and hone your intuition for identifying impactful applications of high-performance 3D printing in your operations. Program content includes lectures, real-world demos and case studies, guided tutorials in both Markforged's Eiger software and CAD, and much more.

Completion of this training program prepares you to take the Markforged Certified Additive Expert exam in Composites (MCAE-C), which will be administered at the end of formal instruction.

#### Markforged University Composites-trainingsprogramma

Het Composites-trainingsprogramma is ontworpen om u te helpen de vaardigheden op te bouwen en te ontwikkelen die nodig zijn om te profiteren van Markforged composiet versterkte 3D-printtechnologie om uw dagelijkse technische of technische werk te versnellen en te vereenvoudigen. In dit driedelige trainingsprogramma, bestaande uit Core, Essential en Advanced Composites, zullen uw instructeurs u begeleiden bij het verkennen van de fundamentele werkingsprincipes van Markforged composiet 3D-printen, het ontwikkelen van uw vaardigheden in Design for Additive Manufacturing (DfAM) en het aanscherpen van uw intuïtie voor het identificeren van impactvolle toepassingen van high-performance 3D-printen in uw activiteiten. De inhoud van het programma omvat lezingen, real-world demo's en casestudy's, begeleide tutorials in zowel Markforged's Eiger-software als CAD, en nog veel meer.

De voltooiing van dit trainingsprogramma bereidt u voor op het Markforged Certified Additive Expert-examen in Composites (MCAE-C), dat zal worden afgenomen aan het einde van de formele instructie.

Markforged Trainings center

<https://markforged.litmos.com/home/dashboard>

[Showpad Web](#)

rveenstra@aletta.nl

Ruben22!

Metal

**GO TO PATH**

Markforged University Core Composites

C.1.3. Fused filament Fabrication (FFF)

C1.3 - Intro to Fused Filament Fabrication (FFF)

### Feature Fidelity in X, Y and Z

Hole, cross section in **XY** plane

Hole, cross section in **XZ** plane

Markforged University



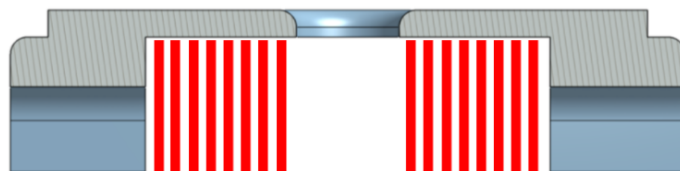
## What about overhangs?



- 3D prints are built layer by layer on **top** of the preceding layer
- Cantilevered or overhanging features may be built on top of **supports**

- Cantilevered = vrijdragend
- Preceding = voorgaande

## What about overhangs?



- 3D prints are built layer by layer on **top** of the preceding layer
- Cantilevered or overhanging features may be built on top of **supports**

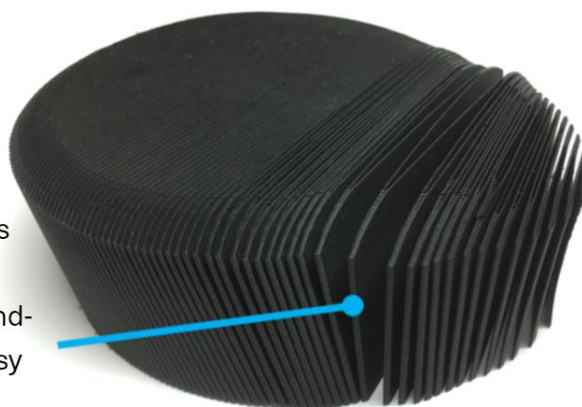
Support material is added automatically in Markforged's Eiger slicing software



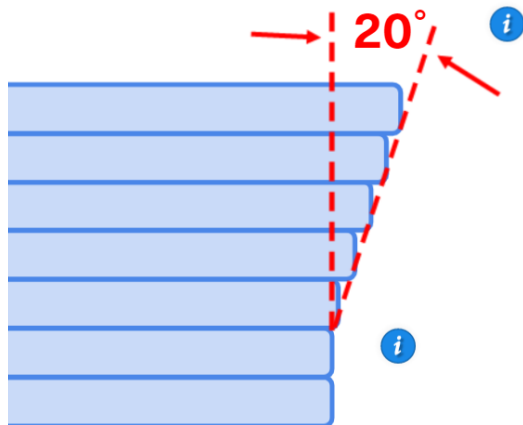
- Houd, bij CAD, rekening met printoriëntatie, om support material te reduceren.
- Idem: richting van belasting.

Plastic Supports Have an Accordion Shape

Notice the supports are connected in a continuous back-and-forth pattern for easy removal

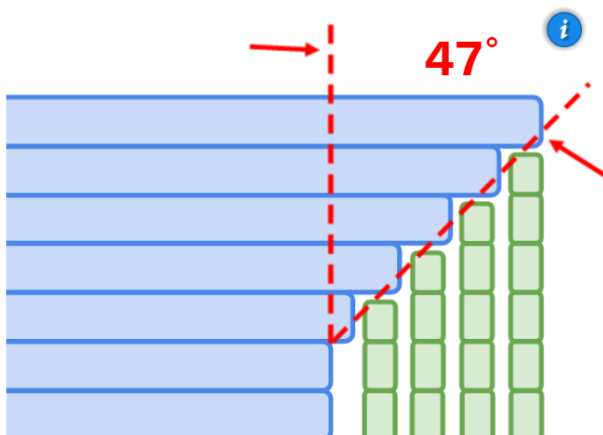


## Want to Avoid Supports? Remember the 45° Rule



- Hoek  $\leq 45^\circ$ .

## Supports are Generated Past 45°



At  $>45^\circ$  from the vertical, each new layer projects too far to self-support  
Support material is automatically generated in software to maintain part quality

- Langere printtijd.
- Meer materiaalverbruik, door support.
- Dus duurder.

## Markforged FFF Filaments



**Onyx**



**Nylon  
White**



**Onyx FR**

- Onyx: Carbon filled nylon.
  - Hoge taaiheid.
  - Afbuiging T?
  - Embrace??
  - Hoge nauwkeurigheid en oppervlaktegesteldheid.
  - Toepassingen:
    - Fixtures, prototypes.
    - Vervanging voor kunststoffen: Nylon en Delrin.
- Nylon White.
  - Unfilled material.
  - Geschikt voor modellen.
  - Lower friction properties,
  - Niet geschikt voor overhang  $> 57^\circ$  and thin parts.
  - Slippery surface finish.
- Onyx FR.
  - Low flamability.
  - Thickness of 3mm.
  - Toepassingen: Aerospace, Defence and Transportation.
    - Exposing to high heat.
    - Bestand tegen combustion (verbranding): vonken en nabijheid van vlambooglassen.
  - Alleen voor industriële toepassingen.

## Recap: Print Orientation Drives Four Things



**Supports**



**Z-axis  
Direction**



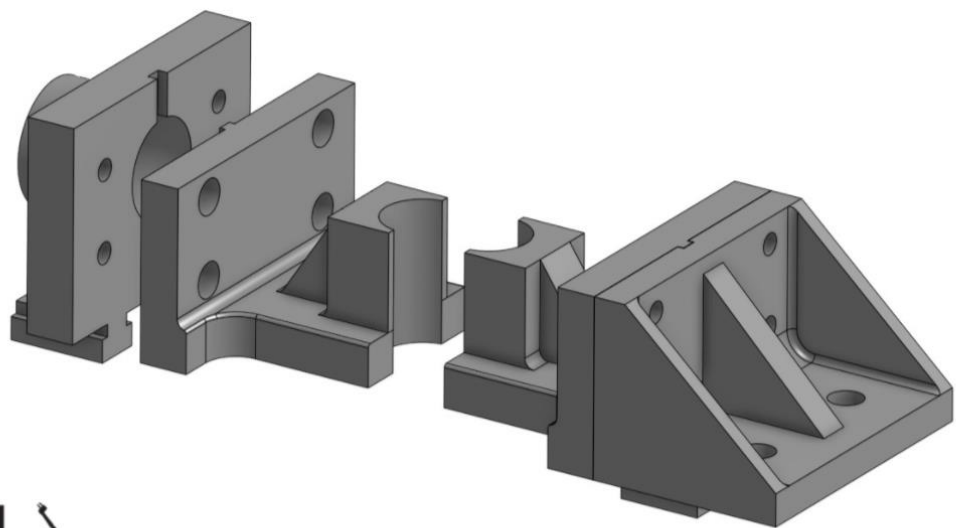
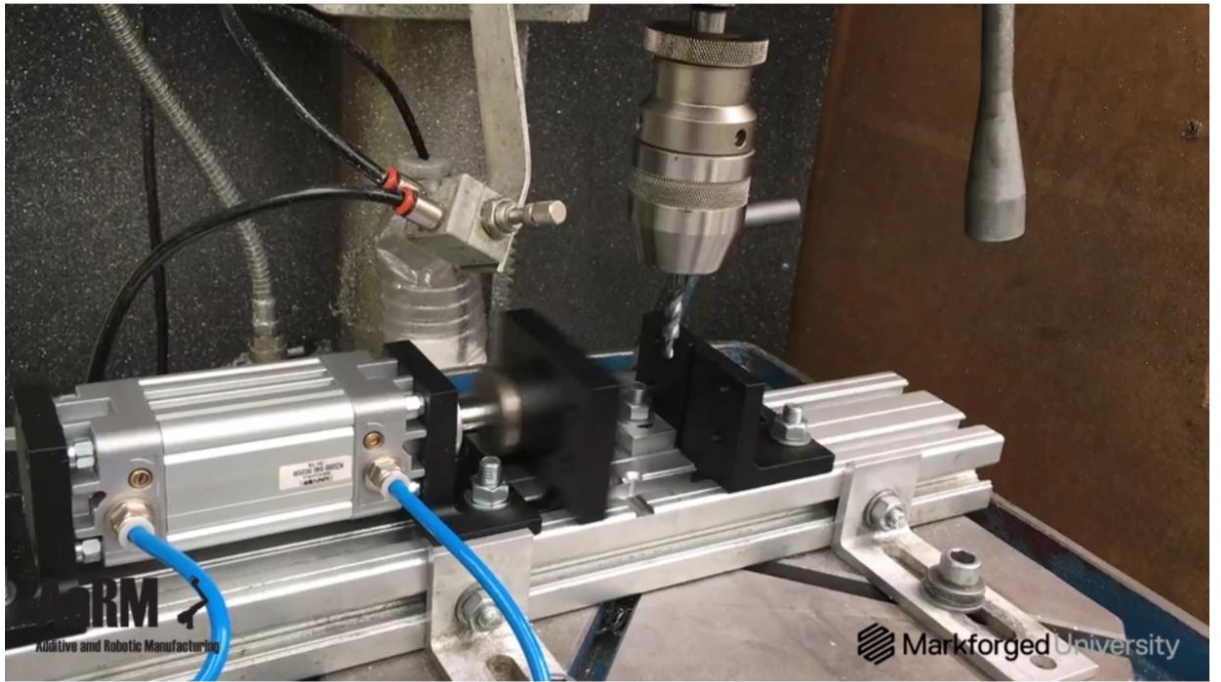
**Horizontal  
Features**



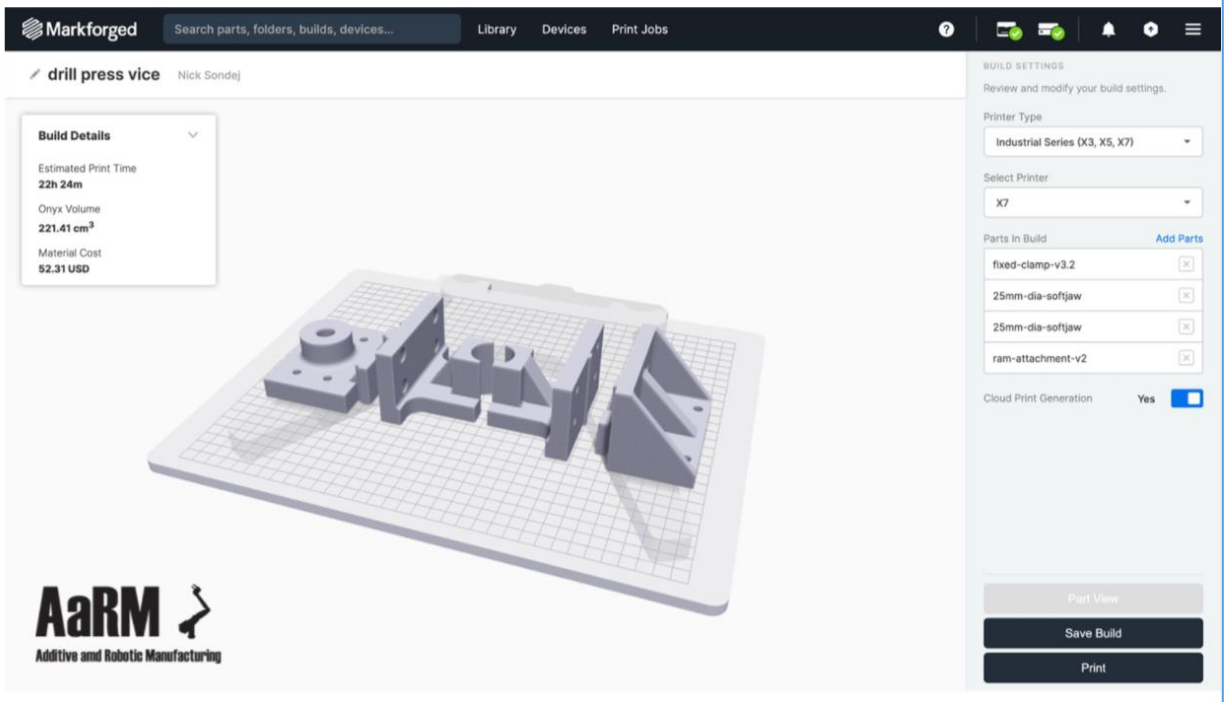
**Fiber  
layout**

FFF in Practice

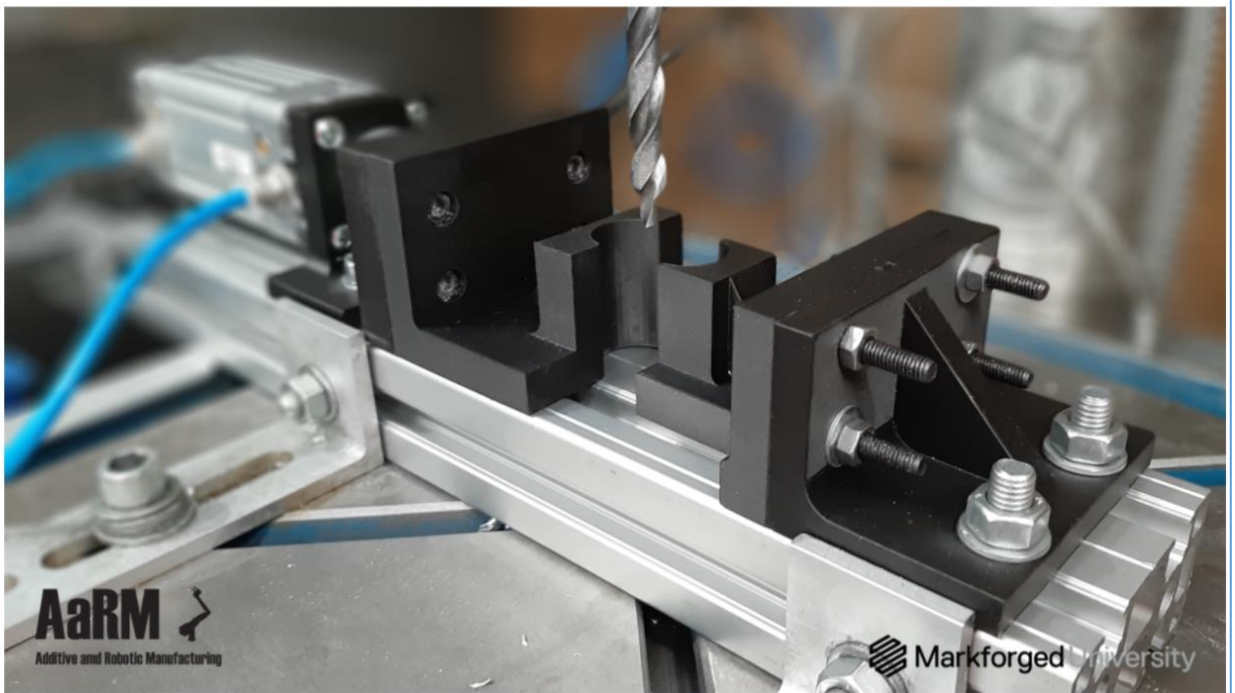
**Example: soft jaw construction with Onyx only**







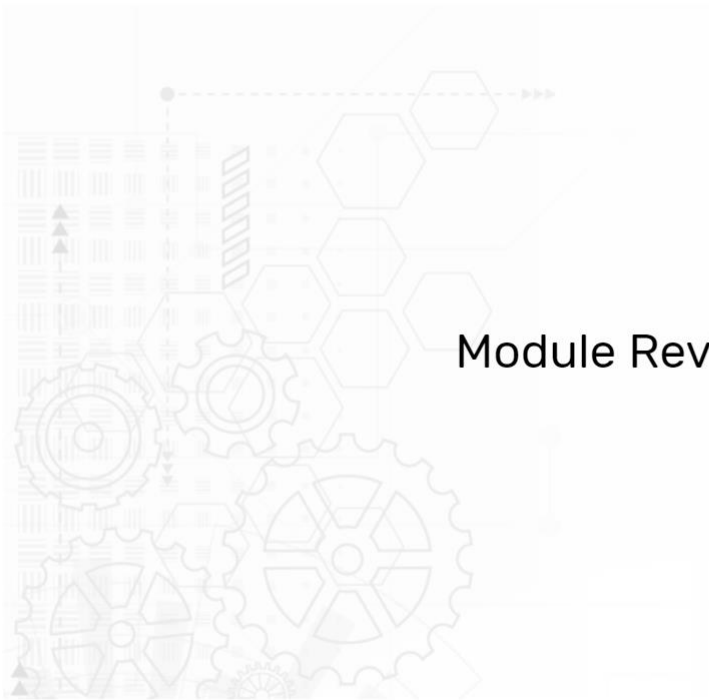
- Quick response tot he customer.



- Realise:
  - Higher strenght than credits you give for.
  - Reduce of material costs and production time.







## Module Review

Mark all answers which are aspects of the plastic FFF printing process that you need to consider when choosing a print orientation for a Markforged printer.

- Printhead location
- Supports and their location
- Z-axis strength
- Horizontal features and their functional requirements
- Plastic FFF material selection

Mark all answers which are aspects of the plastic FFF printing process that you need to consider when choosing a print orientation for Markforged printers

- Printhead
- Supports
- Z-axis strength
- Horizontal orientation
- Plastic FFF material selection



Correct

You're correct – nicely done!

Continue

True/False: Markforged's Eiger software automatically generates support structures for any overhanging features with a surface tangent angle greater than 45° from the **vertical**.

- True
- False

3D printed parts are **anisotropic**, which means that they...

- don't absorb moisture readily
- don't have a crystalline structure seen in isotropic plastics
- have different mechanical properties in different directions
- perform best in outdoor environments near the Equator

Click on any geometry in this part which is an example of a **horizontal feature** whose functional requirements should be considered in the current print orientation.



- Boven

## Results

Your Score: 100% (40 points)  
Passing Score: 80% (32 points)

---

### Result:

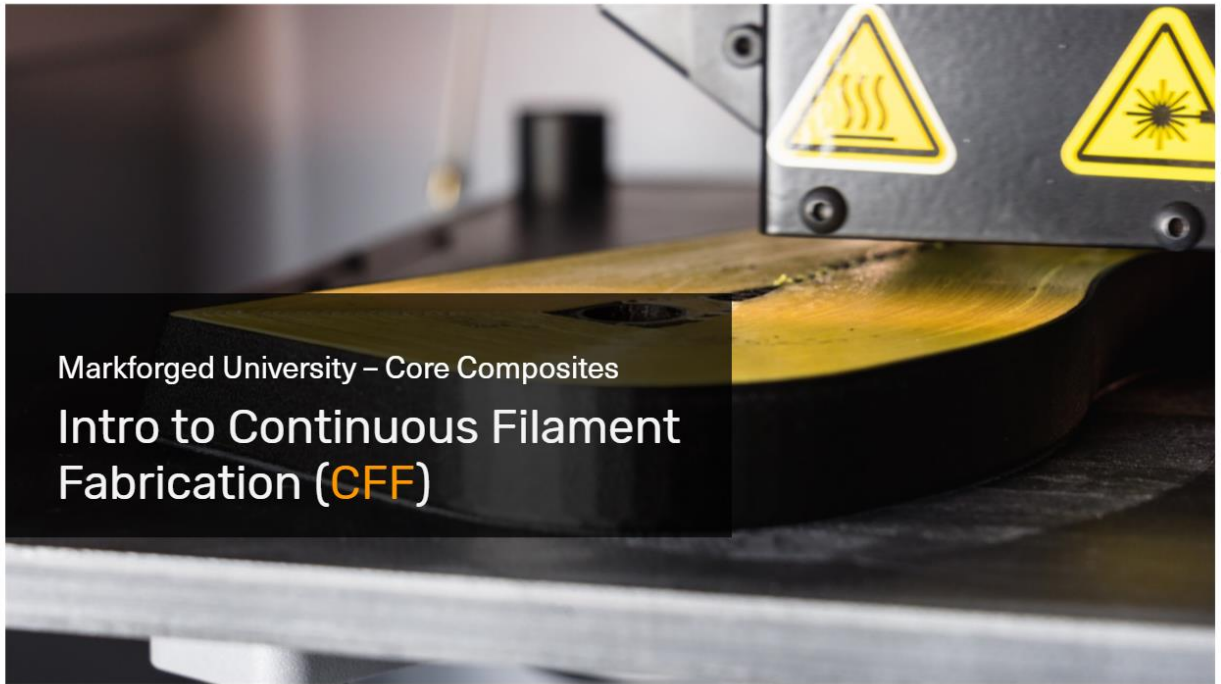


Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

## C.1.4. Continues filament Fabrication (CFF)



Markforged University – Core Composites  
**Intro to Continuous Filament  
Fabrication (CFF)**

## Module Overview

CFF Process Overview

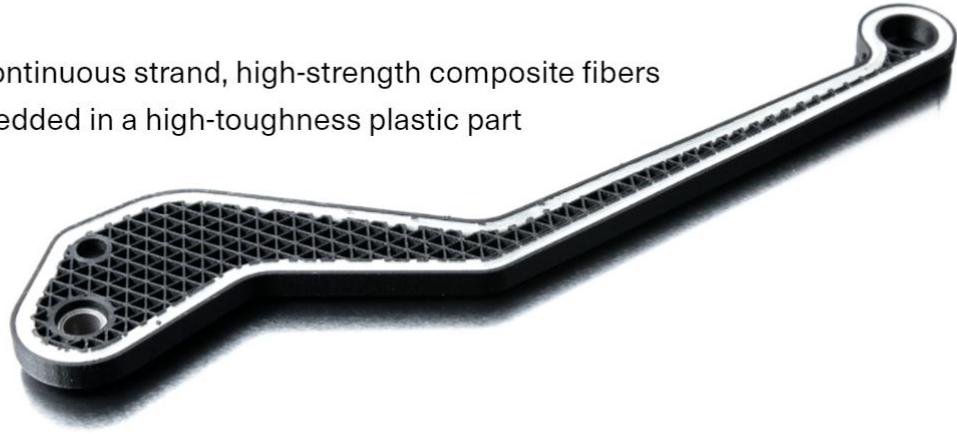
A Closer End-to-end Look at CFF

Mechanics of CFF Reinforcement in X, Y and Z

CFF in Practice

## Q: What is CFF reinforcement?

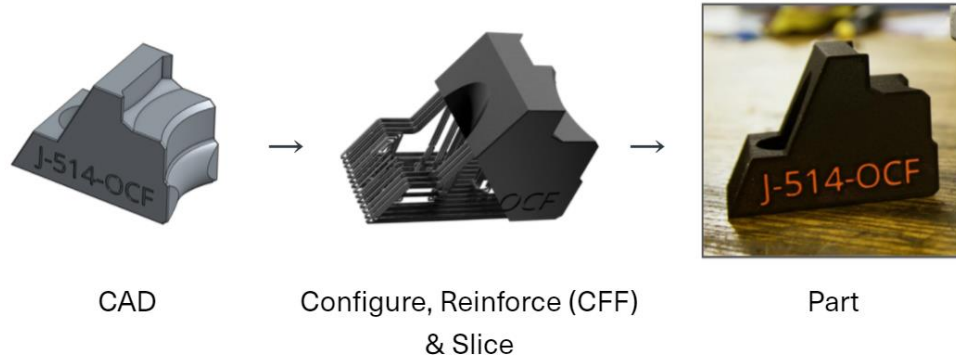
A: Continuous strand, high-strength composite fibers embedded in a high-toughness plastic part



- Strand = Streng.



## FFF+CFF Process Overview



CFF produces parts which are true composites

## Composite (*noun*):

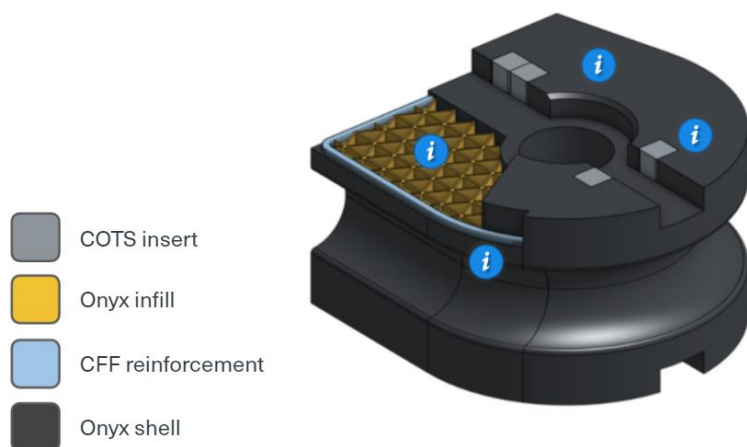


A solid material which is composed of **two or more substances** having **different physical characteristics** and in which each substance **retains its identity** while contributing **desirable properties to the whole**



- Een vaste stof die is samengesteld uit twee of meer stoffen met verschillende fysieke kenmerken en waarbij elke stof zijn identiteit behoudt en tegelijkertijd gewenste eigenschappen aan het geheel toevoegt.

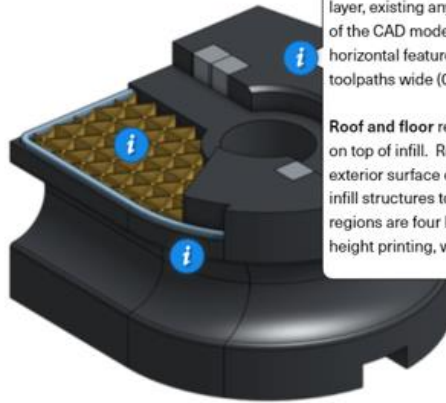
## Anatomy of an FFF + CFF Part





## Anatomy of an FFF

-  COTS insert
-  Onyx infill
-  CFF reinforcement
-  Onyx shell



### Outer Shell

By default, Markforged composite 3D printers build all parts with an outer shell of plastic FFF material through two different structures – walls and roof/floor layers.

**Walls** are the printed borders of the geometry of every printed layer, existing anywhere the layer cross section meets a surface of the CAD model. They form the exterior surface of any non-horizontal feature in the part. By default, walls are printed two toolpaths wide (0.8 mm, 0.031 in) in the XY plane.

**Roof and floor** regions are the areas in a layer underneath and on top of infill. Roof and floor regions form the horizontal exterior surface of the part and transition the top and bottom of infill structures to exterior surfaces. By default, roof and floor regions are four layers thick, except for 50 um (0.002in) layer height printing, where they are eight layer thick



- Exterior = buitenkant

## Anatomy of an FFF + CFF Part

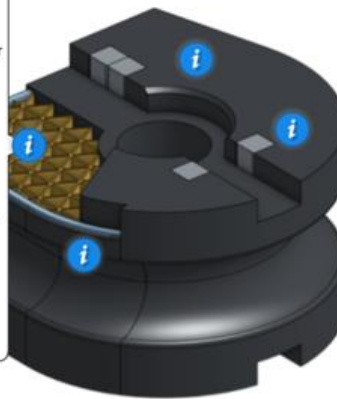
### Infill

All Markforged composite parts are printed by default with a hollow triangular infill structure like you see here. The infill structure makes the part lighter, uses less material and prints much faster and critically, results in only a minor loss in bulk part strength compared with the reduction in material used as compared to a solid part.

We'll cover this in further detail later in the course, but for now, know that infilled parts remain comparatively strong despite using much less material because many loading conditions apply forces across the surface of a part, rather than internally, where the part is hollow.

You have control over the infill density (including printing solid parts) and infill pattern in Markforged's Eiger software platform.

-  Onyx shell



## Anatomy of an

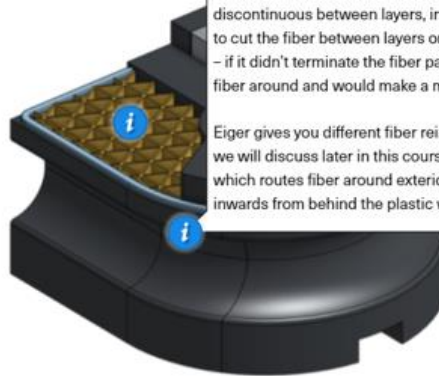
### CFF Composite Reinforcement

CFF reinforcement adds long continuous strands of composite fiber throughout individual layers to add high strength to the part.

CFF reinforcement is continuous throughout a layer or regions of a layer (depending on layer geometry and fiber reinforcement strategy) but is discontinuous between layers, in the Z-axis. Your composite 3D printer needs to cut the fiber between layers or regions of layers in order to continue printing – if it didn't terminate the fiber path it would be dragging a continuous strand of fiber around and would make a mess.

Eiger gives you different fiber reinforcement techniques to choose from that we will discuss later in this course. Seen here is a 'Concentric Fiber' pattern, which routes fiber around exterior geometries in concentric rings, moving inwards from behind the plastic walls of the layer towards the inside of the part

-  COTS insert
-  Onyx infill
-  CFF reinforcement
-  Onyx shell



- Continuous strands?

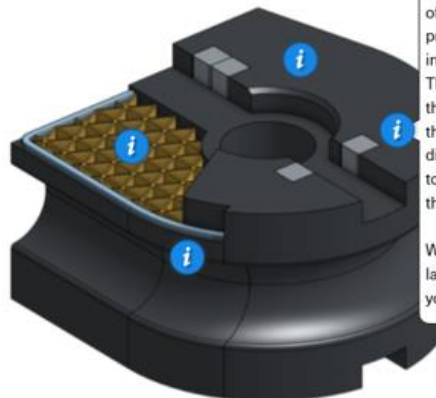
## Anatomy of an FFF + CFF Part

### Off-the-Shelf Inserts

Throughout this course and in future work, we will often find that a part needs functionality or properties that simply can't be 3D printed such as increased wear resistance or surface hardness. The easiest and most efficient way to provide these capabilities is to integrate commercial off-the-shelf (COTS) hardware. In the CNC bending die that you see here, we've pressed in shaft keys to distribute loading forces more evenly throughout this part.

We'll discuss this technique in much more detail later in this course but I'm calling it out here to get you started thinking about it now.

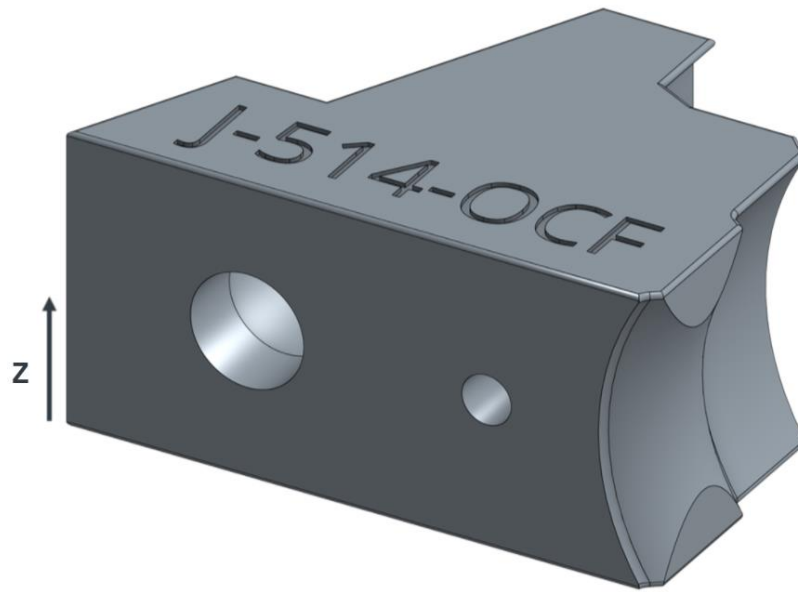
-  COTS insert
-  Onyx infill
-  CFF reinforcement
-  Onyx shell



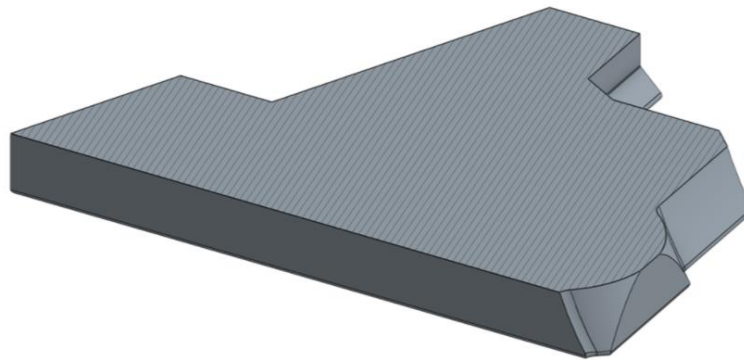


## A Closer Look at the CFF Process

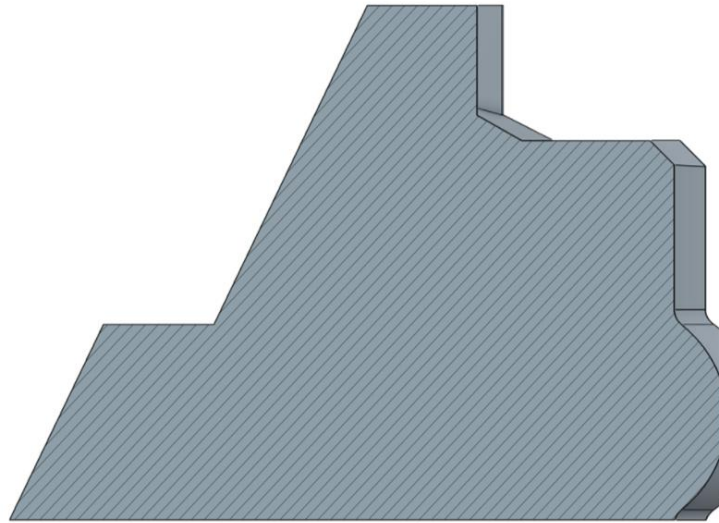




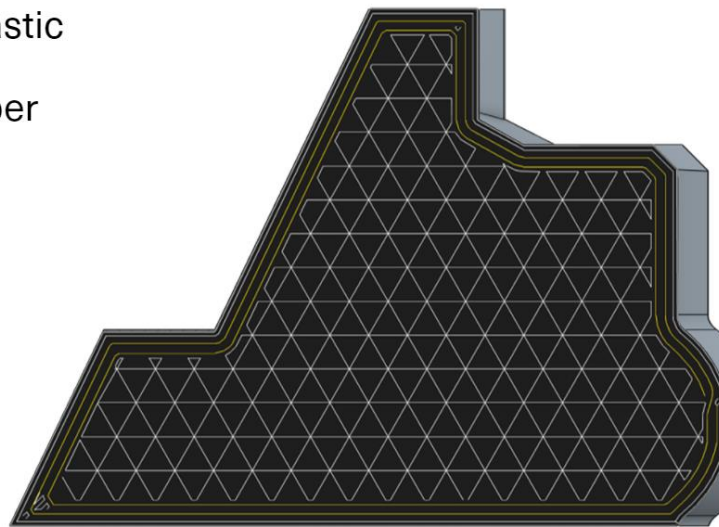
- Kiezen van de juiste oriëntatie.



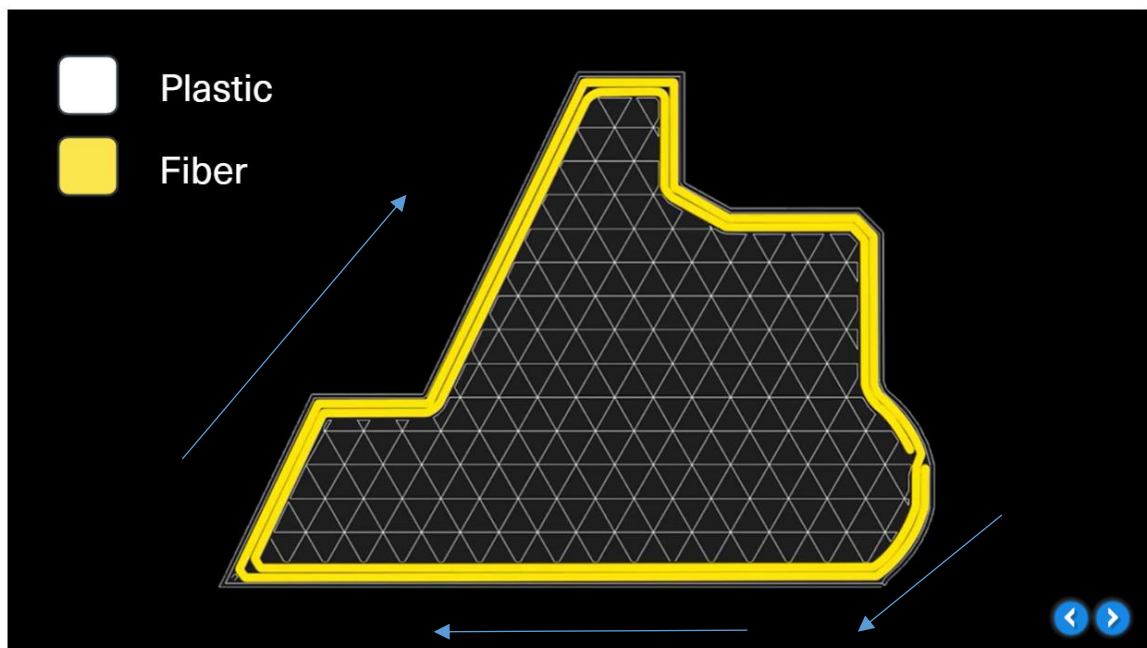
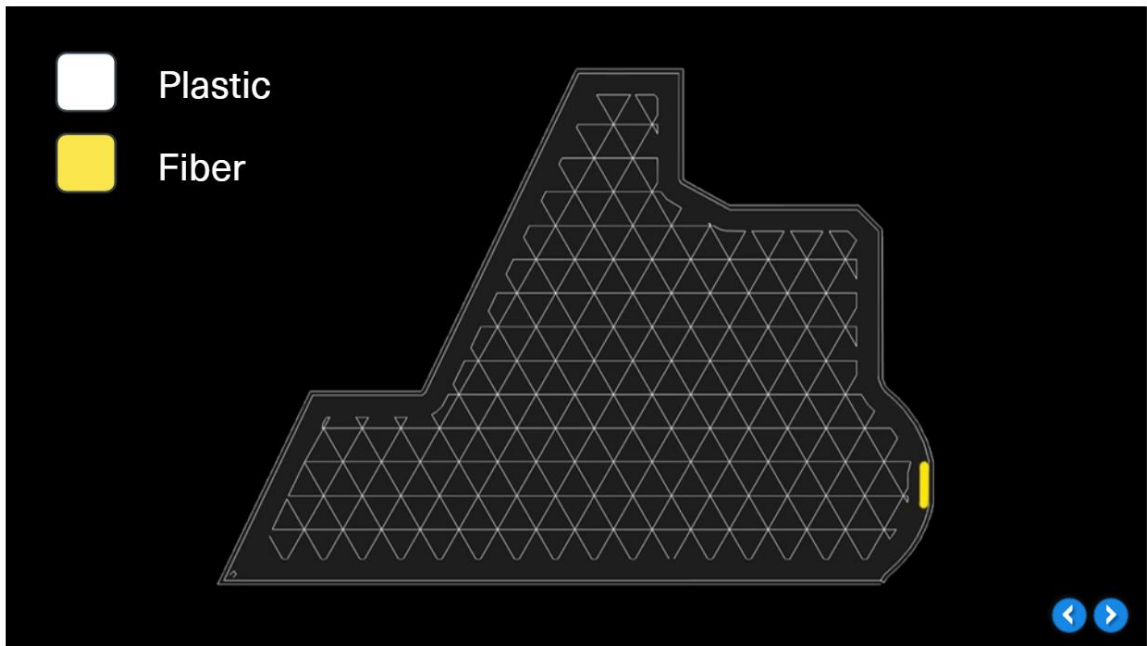
- Slice.



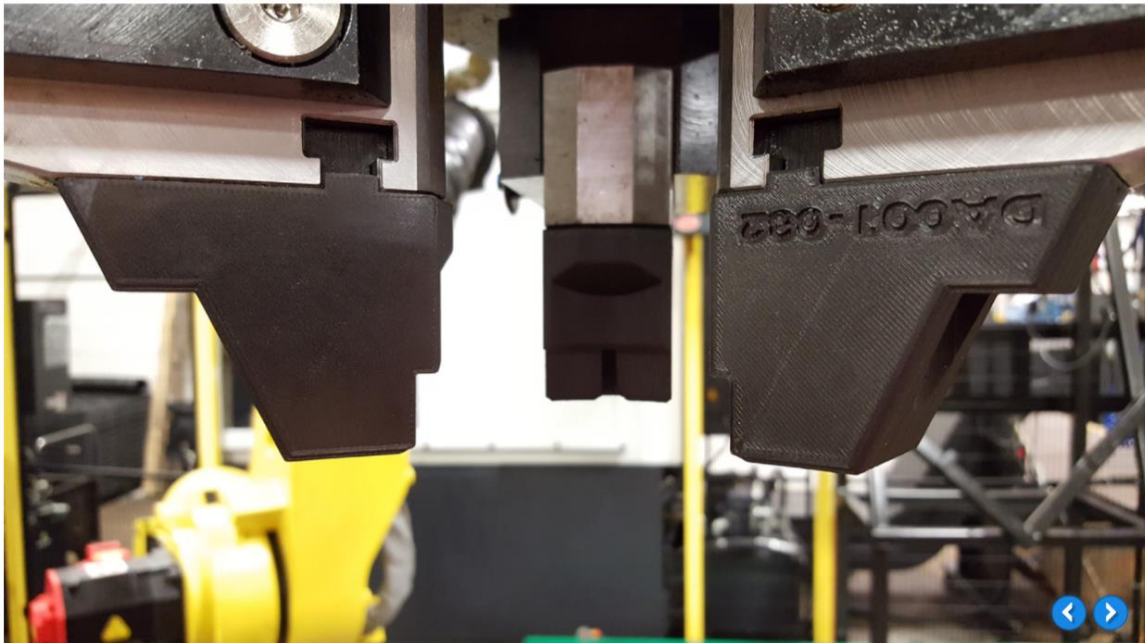
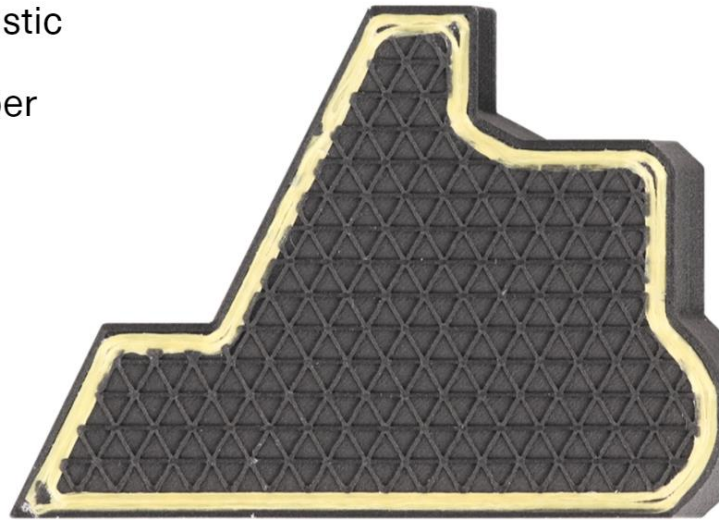
- Plastic
- Fiber

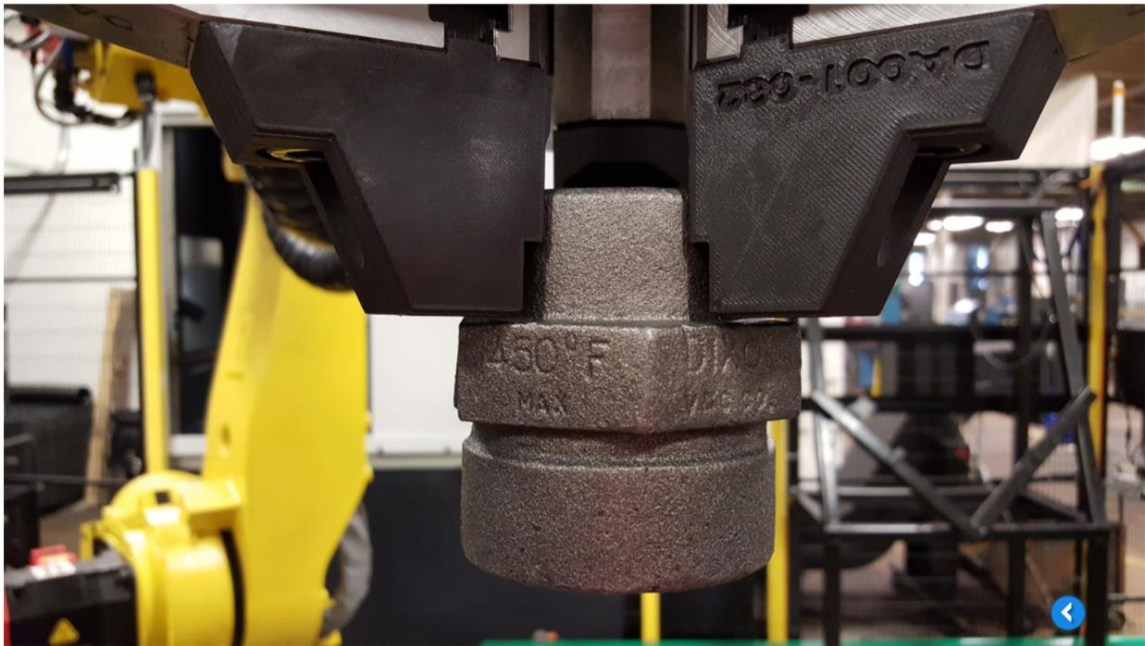






- Plastic
- Fiber





## Types of Fiber

Fiberglass

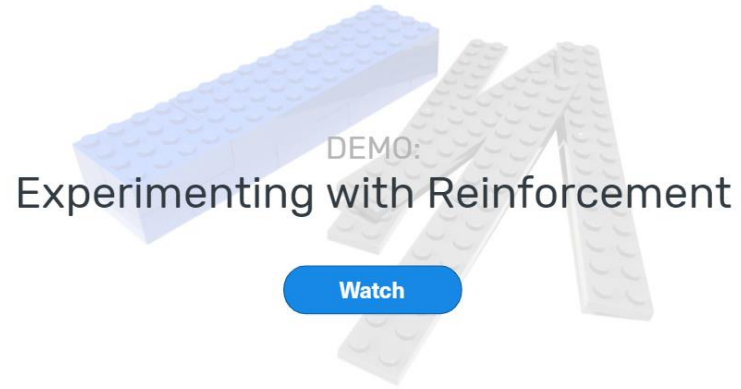
Carbon Fiber

Kevlar

HSHT Fiberglass









- Chopped fibre part

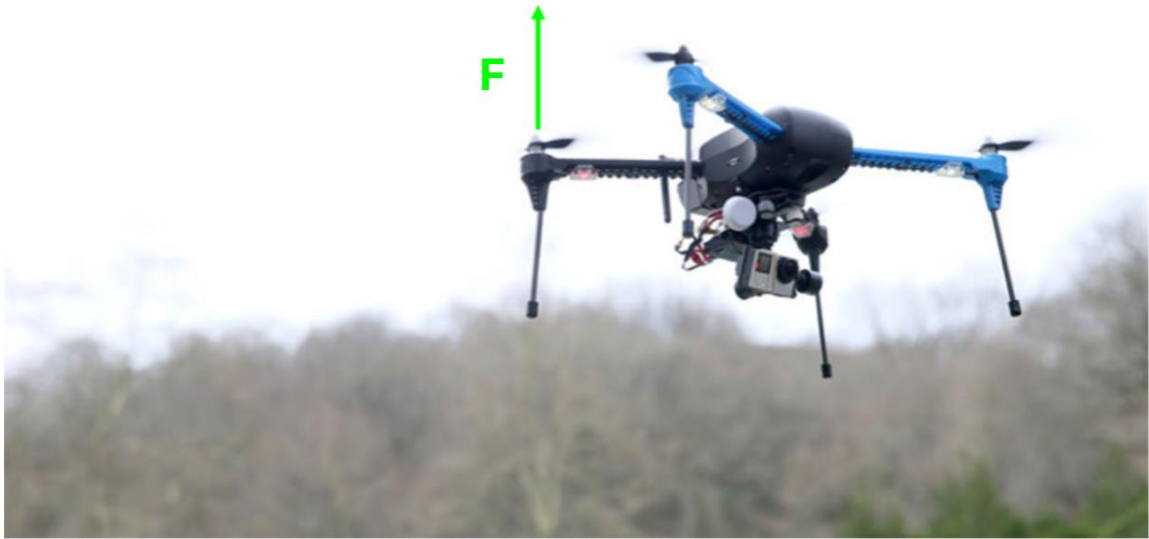


- Part with Continuous layer: bottom and top.

DISCUSSION:  
How did the reinforcement change the part?



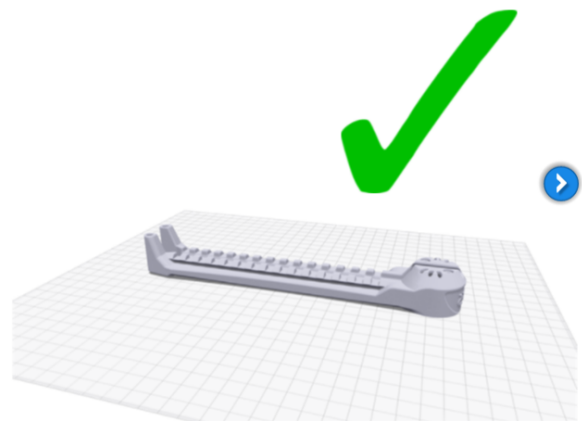
CFF has process limitations too...



## CFF parts are stronger and stiffer in the XY plane

Fiber can span length of drone arm

CFF tensile strength is up to 22x stronger in XY plane than Onyx

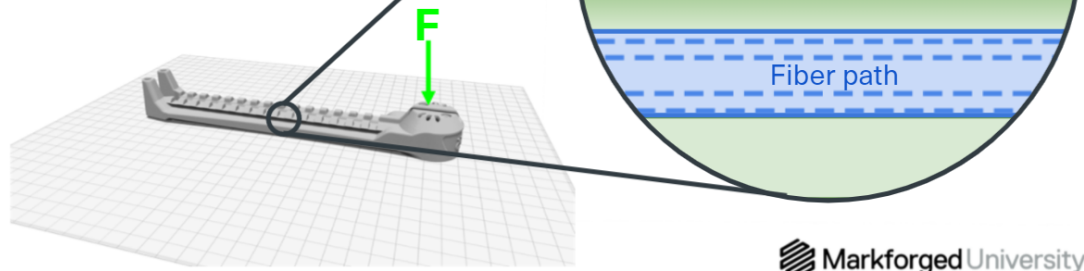


 Markforged University

- Span = omspannen
- Tensile = treksterkte.

Bending force acts on  
entire layer

Fiber put in **tension**

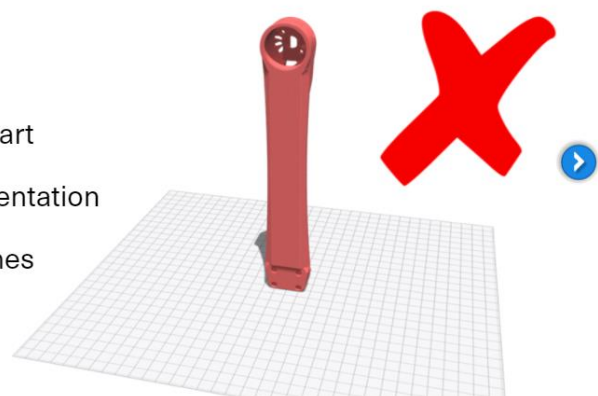


CFF doesn't add strength in the Z-axis

Drone arm bends along length of part

Force applied **between** layers in this orientation

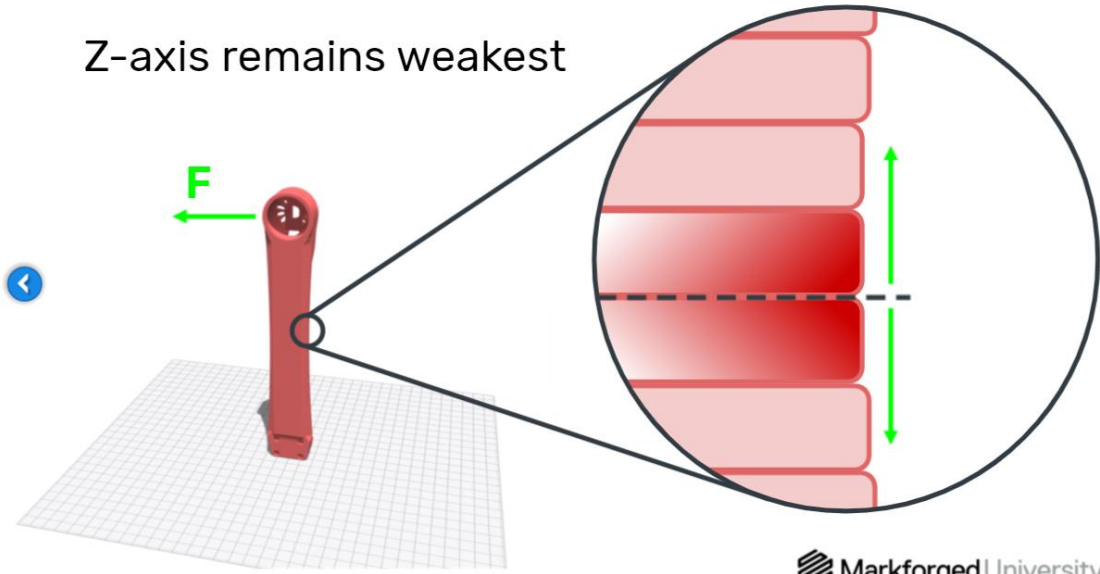
Loading perpendicular to fiber planes



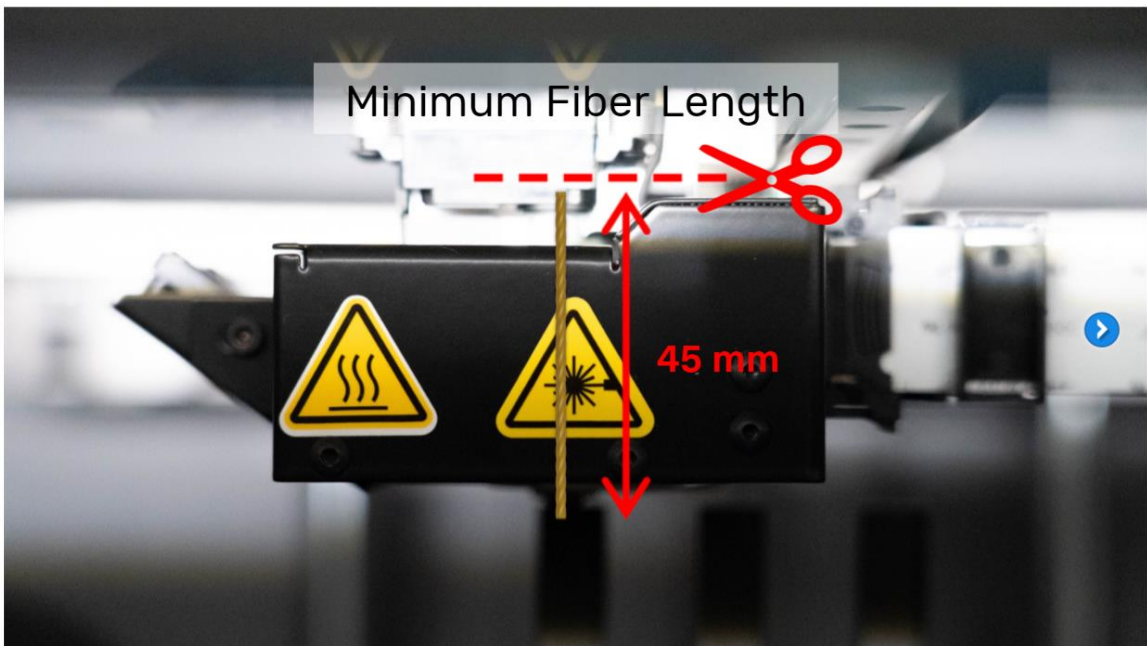
- CFF only in the XY plane.
- Perpendicular = loodrecht.
- Kracht uitgeoefend tussen lagen in deze oriëntatie, loodrecht op vezelvlakken.



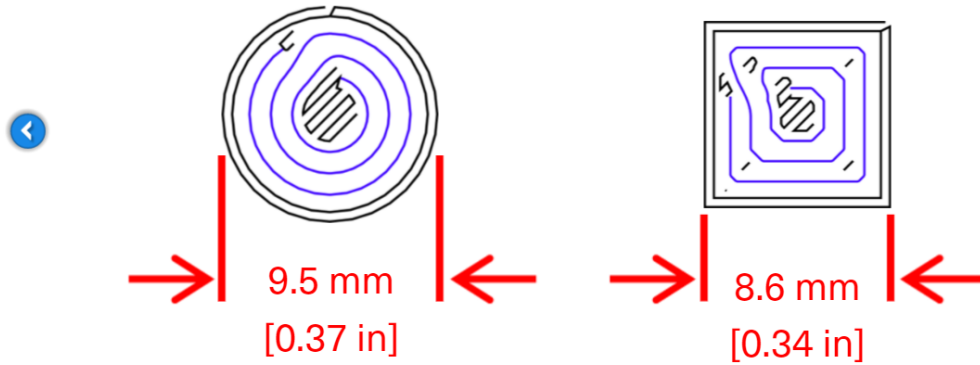
Z-axis remains weakest



Minimum Fiber Length



### Smallest Reinforceable Area



### Minimum Diameters When Reinforcing a Hole

Three rings

$D_3$ : 0.5 mm (0.020")

Two rings

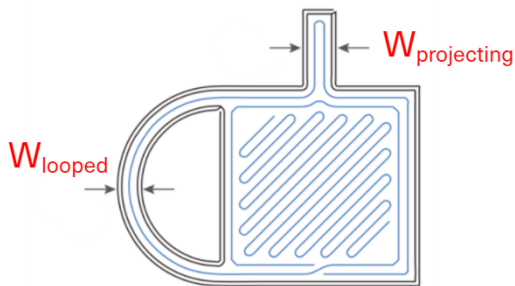
$D_2$ : 3.85 mm (0.152")

One ring

$D_1$ : 12.16 mm (0.479")



## Minimum Feature Sizes for Fiber in the XY Plane



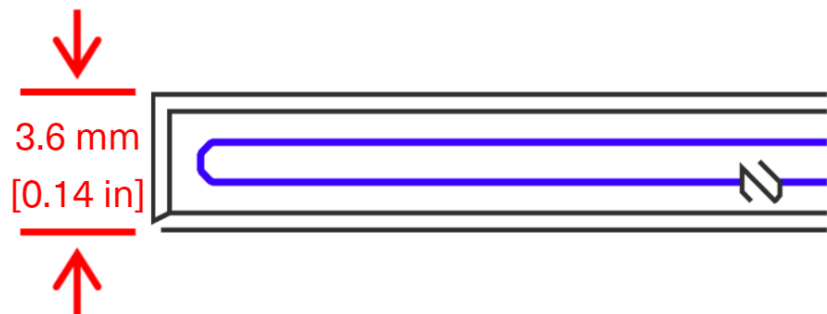
Minimum fiber reinforcement feature width:

Projecting feature  
W: 3.6 mm (0.15")

Looped feature  
W: 2.8 mm (0.11")



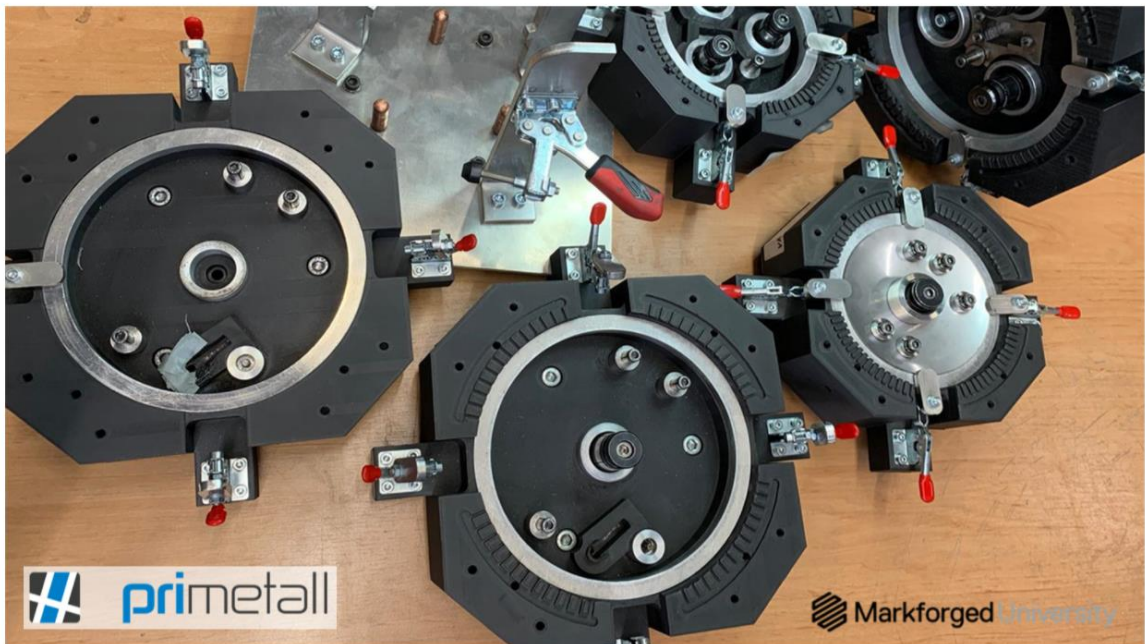
## CFF Fiber Can Bend 180°



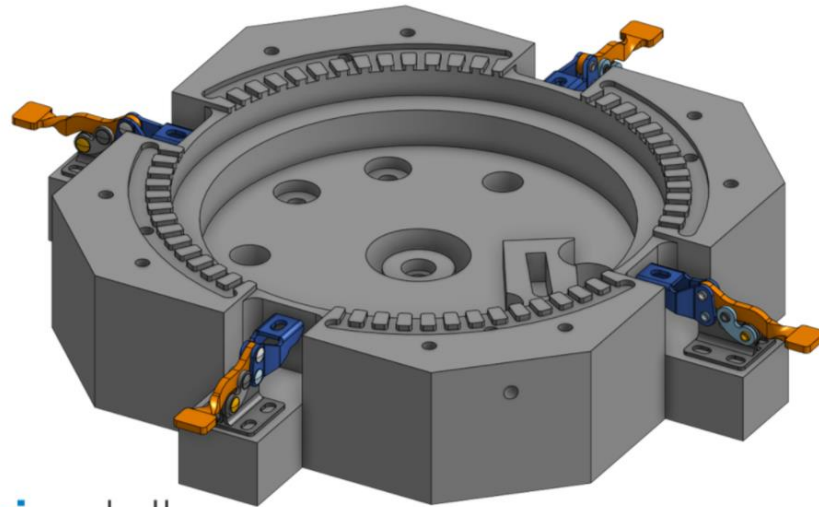




## CFF in Practice



- Laserwelding fixtures.



- CAD-model.

**Part Details**

- Add Description...
- Dimensions: **244.7mm x 244.7mm x 52.0mm**
- Print Time: **4d 19h**
- Material Cost: **238.37 USD**
- Final Part Mass: **923.13g**
- Plastic Volume: **726.05 cm<sup>3</sup>**
- Fiber Volume: **44.56 cm<sup>3</sup>**
- Versions >

**Part Settings**

Review and modify your settings for printing.

General Settings Infill

Reinforcement

Material: **Onyx**

Reinforcement Material: **Fiberglass**

Printer Type: **Industrial Series (X3, X5, X7)**

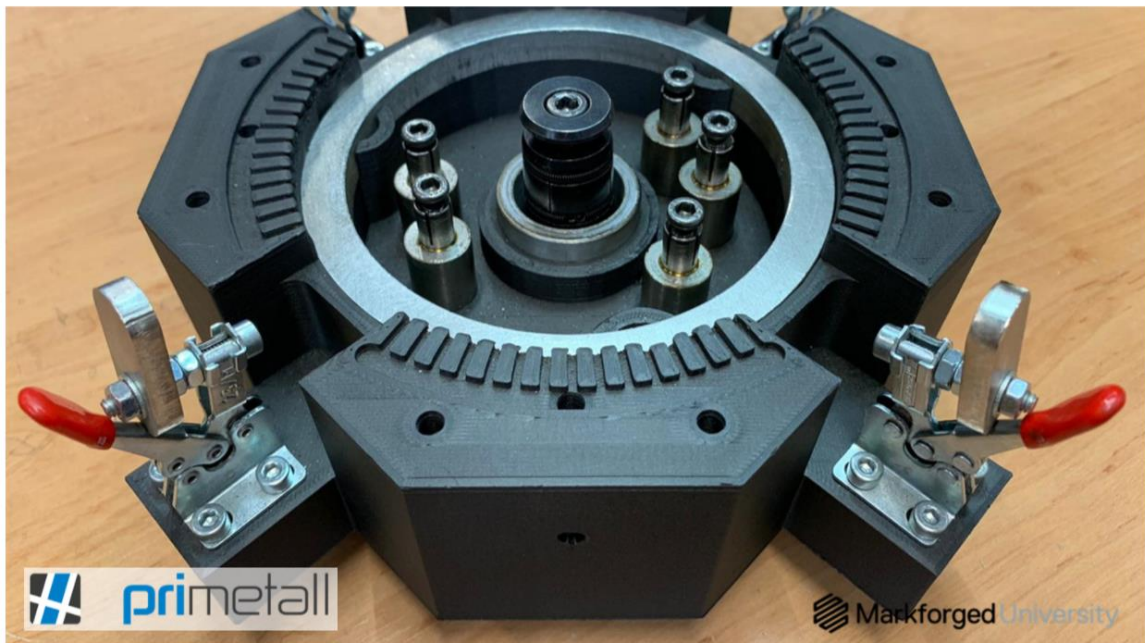
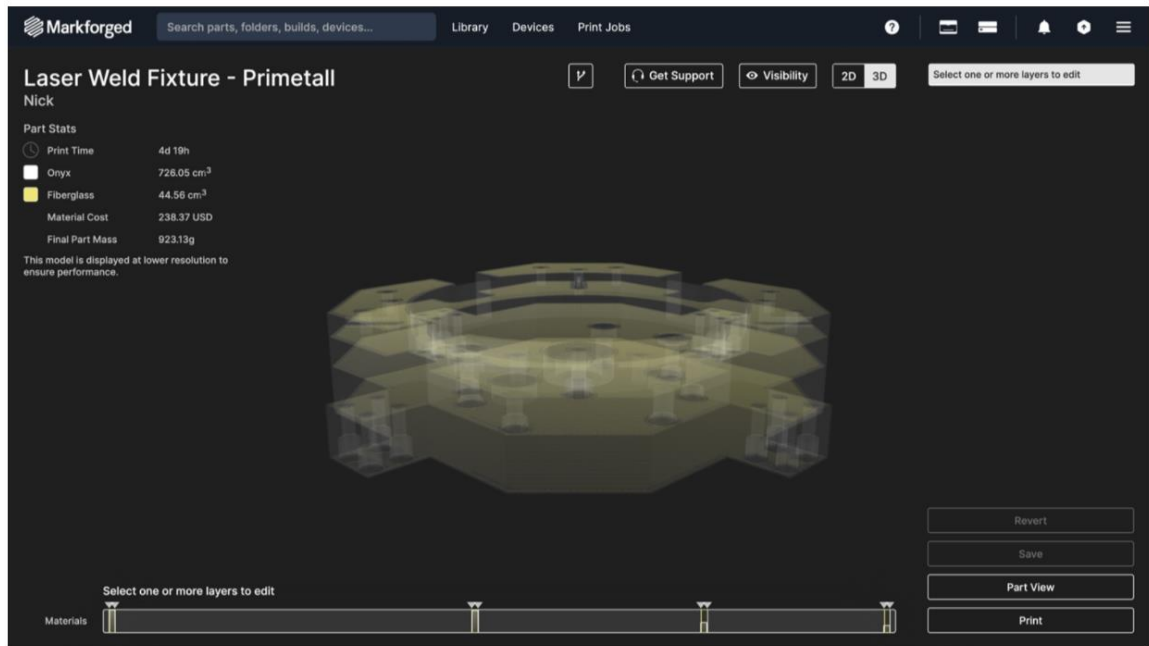
Orientation: **Manual Rotation**

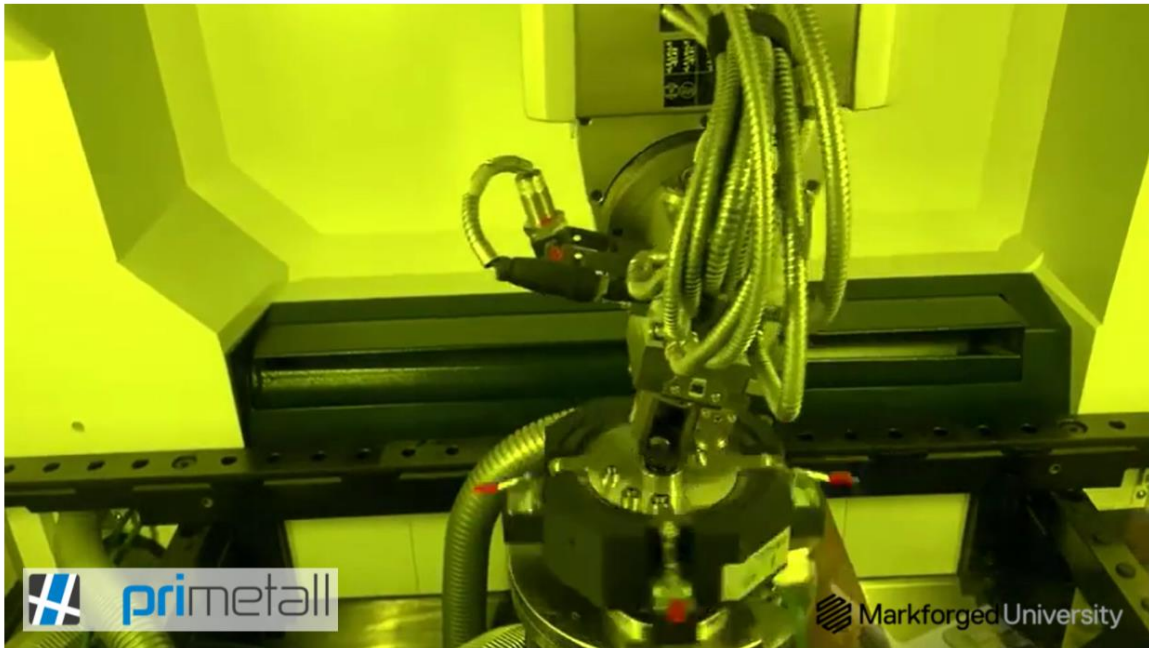
X: 270 Y: 45 Z: 180

Cloud Slicing: **Yes**

Buttons: Save, Internal View, Print

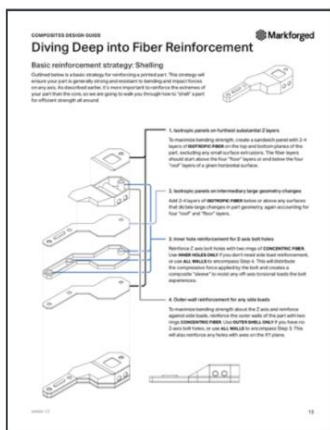
- Upload in Eiger.
- Print time almost 5h.





C.1.4. Design Guide: <https://support.markforged.com/>

## Where to get help – Composite Design Guide



Find at [support.markforged.com](https://support.markforged.com)

Search “composite design guide”



- <https://support.markforged.com/portal/s/>

## Module Review

Which is stronger in the plane of a layer (XY plane), chopped fiber-filled plastics or continuous composite fiber reinforcement?

- Continuous composite fibers (e.g. Carbon Fiber CFF filament)
- Neither, they have the same strength in the XY plane
- Chopped fiber-filled plastics (e.g. Onyx)



True/False: You can print an entire part with just CFF composite filament.

- True
- False

A plastic FFF 3D printed part keeps breaking under load between two of its layers (in the Z-axis). To potentially remedy the problem you should consider:

- Adding CFF fiber reinforcement around the region that is exhibiting failures, since CFF will make the part stronger in the Z-axis
- Giving up on the idea of 3D printing this part and just machining it instead
- Reorienting the part so that the forces are applied more in the XY-plane, and then adding CFF-reinforcement

## Results

Your Score: 100% (40 points)  
Passing Score: 80% (32 points)

---

### Result:

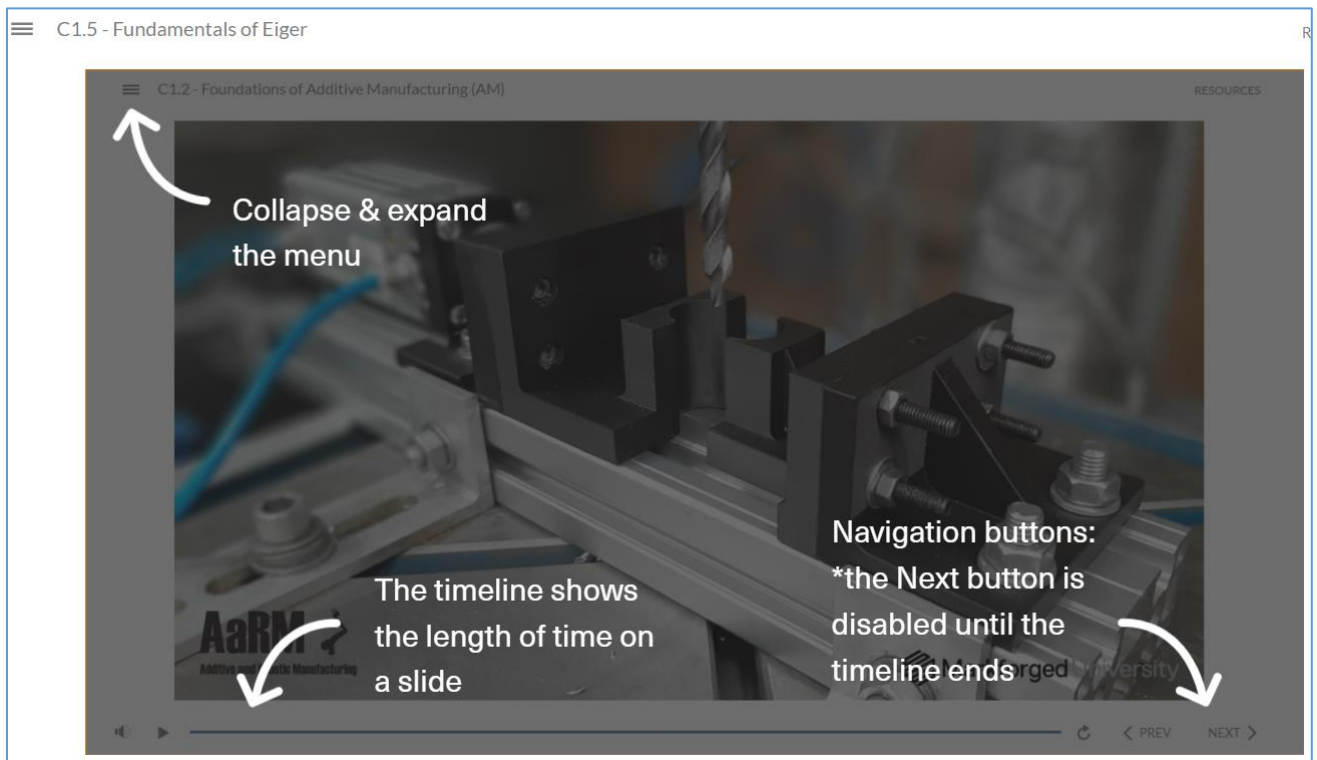
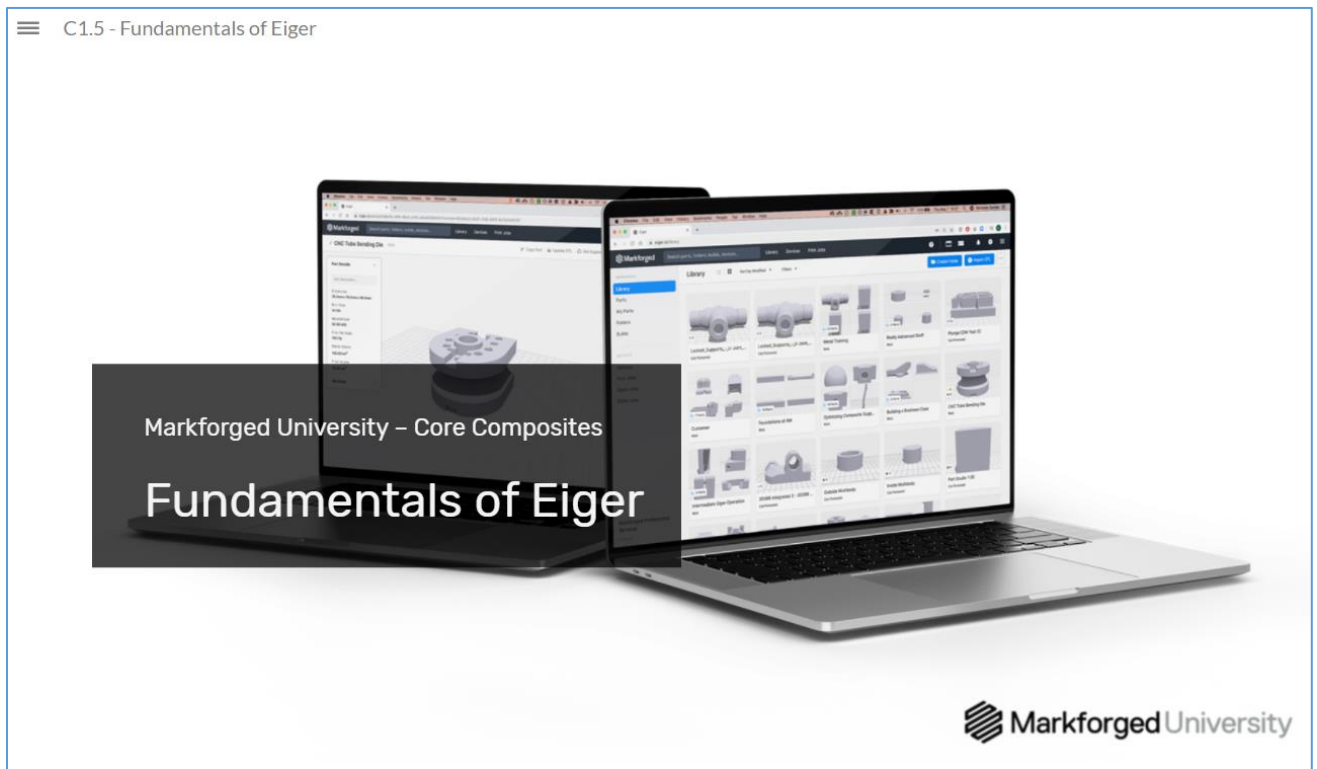


Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

## C.1.5. Fundamentals of Eiger



- Aanwijzingen spreken voor zich.



## Module Overview

Basics of Slicing

Three Roles of Eiger

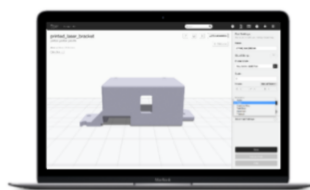
Getting to Know Your Way Around Eiger

Activity: STL-to-Print Eiger Workflow

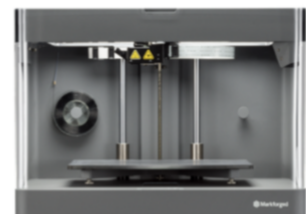
## Review: 3D Printing Process



CAD

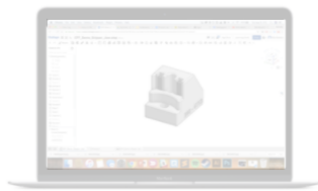


Configure &  
Slice



3D Print

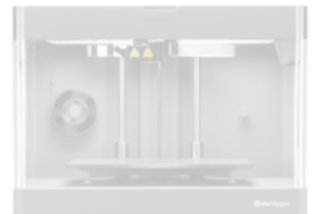
## Review: 3D Printing Process



CAD

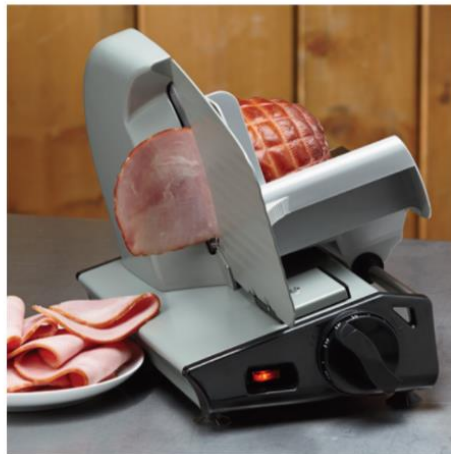


Configure &  
Slice

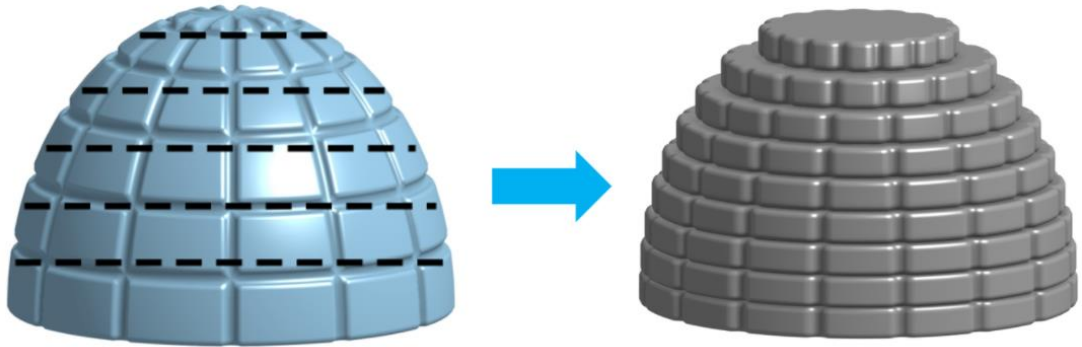


3D Print

## Slicing Is Exactly What It Sounds Like

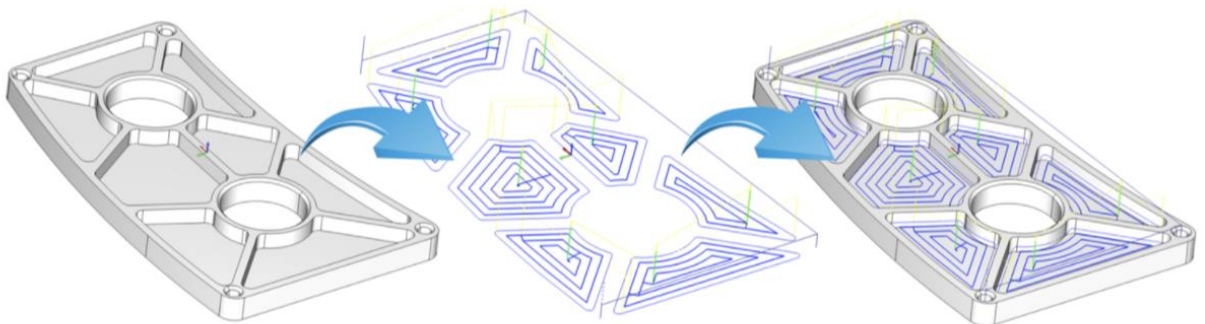


## Slicing Is Exactly What It Sounds Like



- Door de printlayers heeft een geprint model nooit een volledige gladde oppervlaktegesteldheid, zoals getekend in CAD.
- Fidelity = Betrouwbaarheid.
- Familiar proces toolpath similar to CNC-machining CAM.

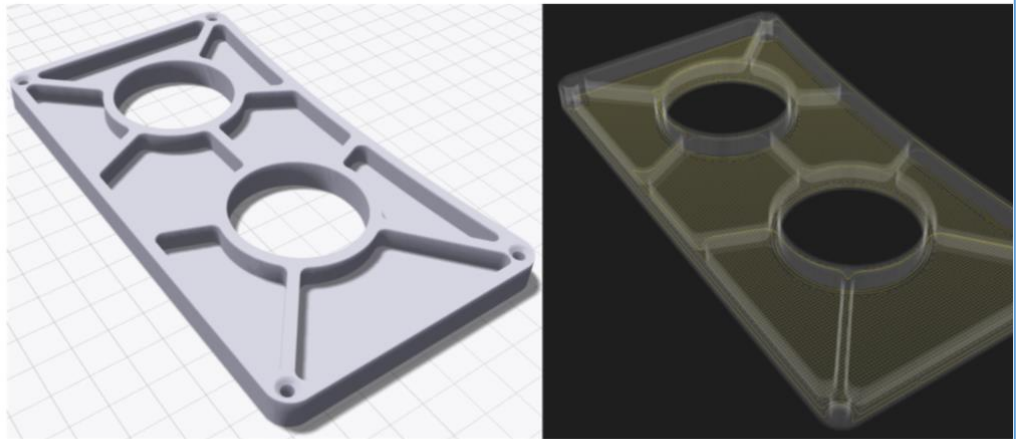
## CNC Machining Has CAM



- CNC-machining programming requires a lot of manual work: Many variables are involved, like:
  - cutting tools.
  - Cutting speed as a result of workpiece material and also cutting tools.
  - Fixing workpieces on the mill.

☰ C1.5 - Fundamentals of Eiger

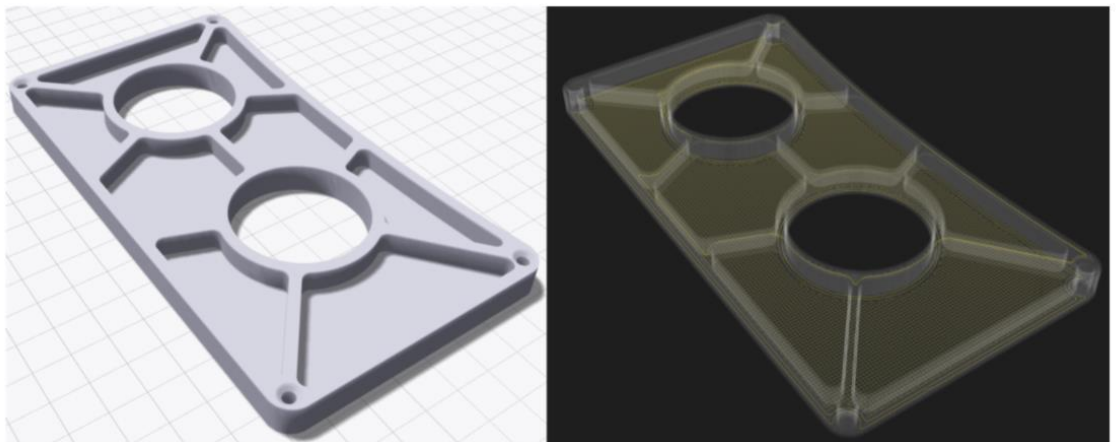
## 3D Printing Has Slicing



 Markforged University

☰ C1.5 - Fundamentals of Eiger

## 3D Printing Has Slicing



 Markforged University

- Much more automatic workflow than CAM-software.
- Only one or two tools to control, wick are the plastic and fibre nozzles.
- Part is printed on the printbed.
- Most parts requires only a few minutes to configure and slice.
- You can leave the printer without supervision.

☰ C1.5 - Fundamentals of Eiger

Eiger has three different roles...



- Three different roles, wick slicing is one of them.

Hover over each feature set of Eiger to learn more about the available capabilities!

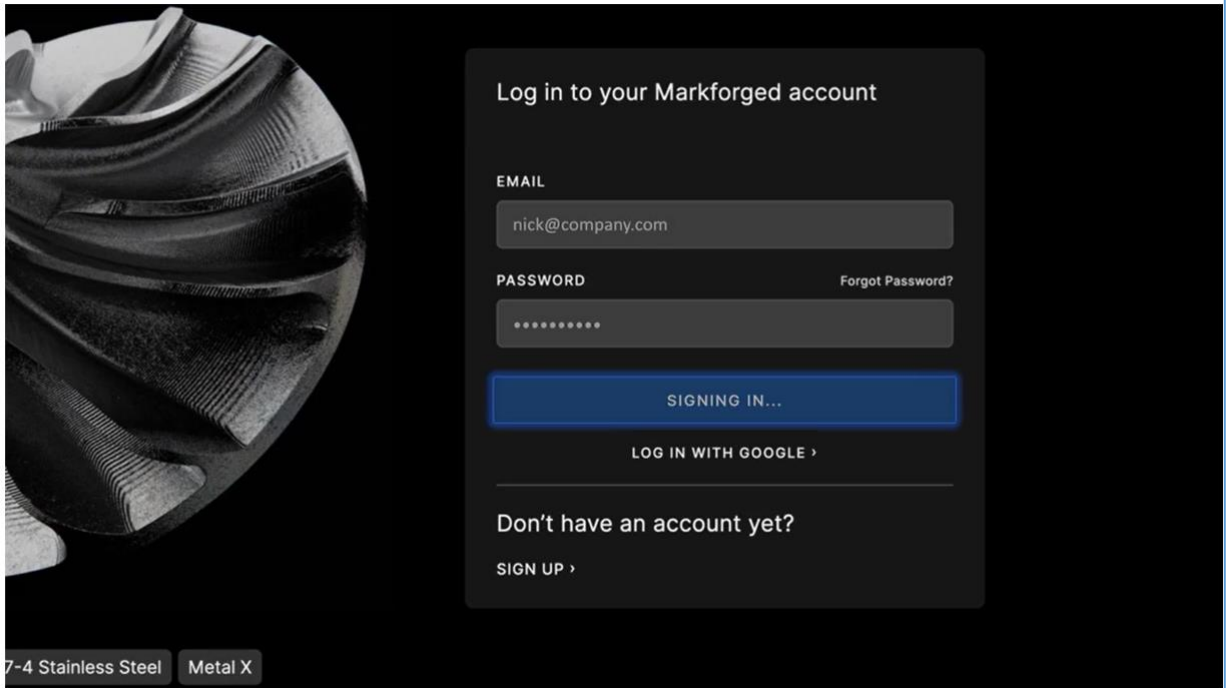
Part Configuration &  
Organization

Print Management &  
Monitoring

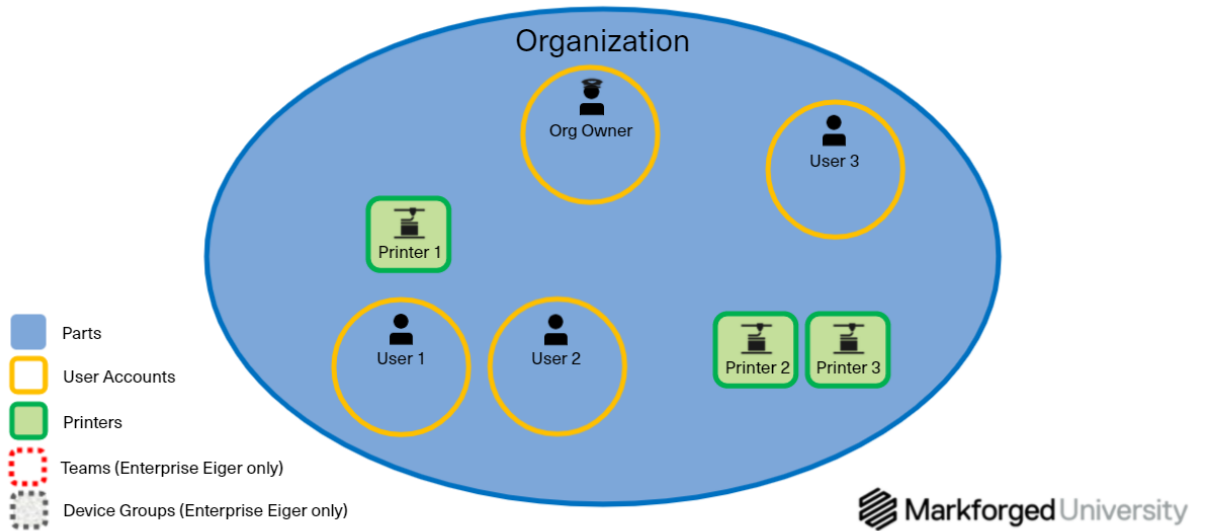
Fleet Analytics &  
Intelligence

- Hover = zweven.

Getting to Know Your Way Around Eiger

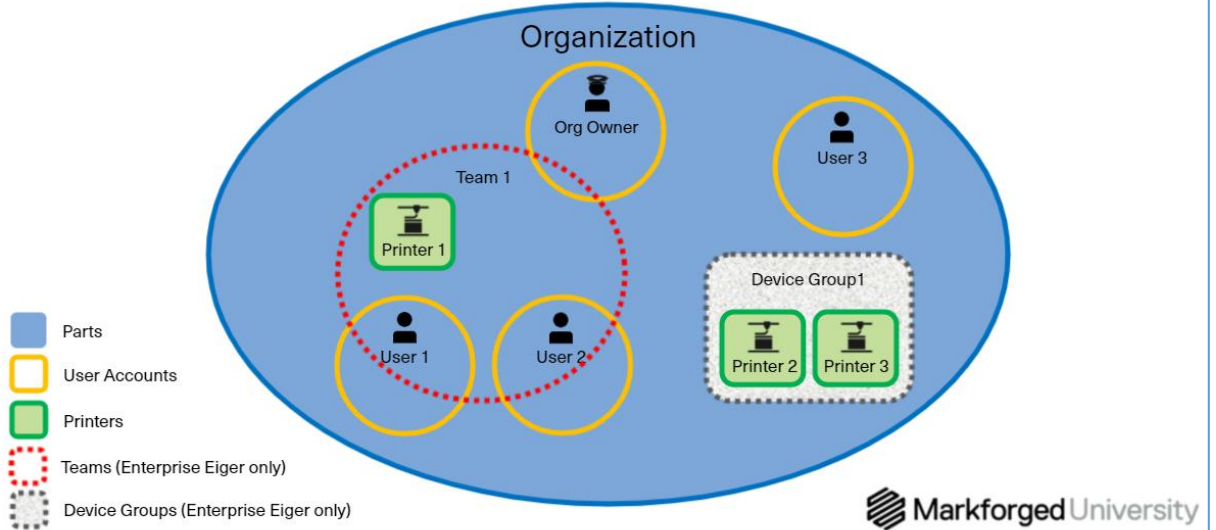


## What's in an Eiger Organization?

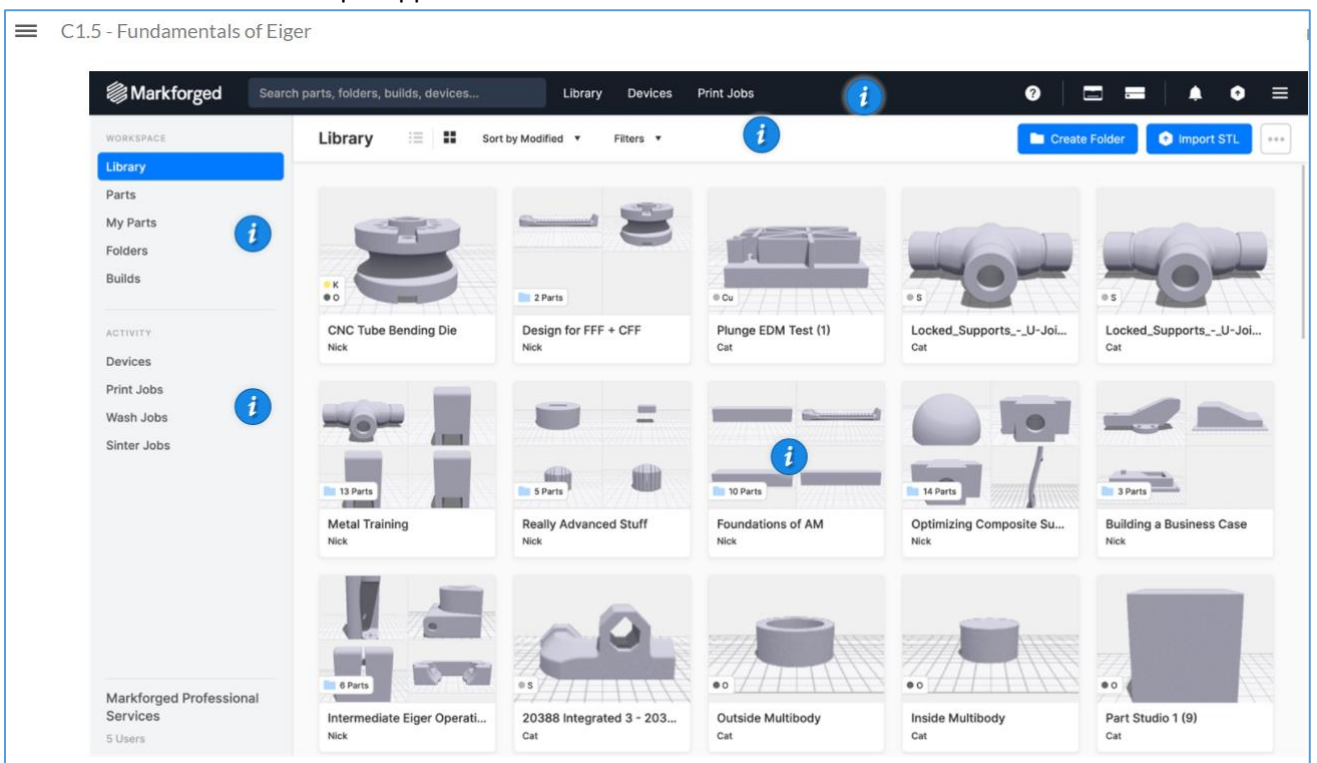


- Enterprise = Onderneming.

## What's in an Eiger Organization?

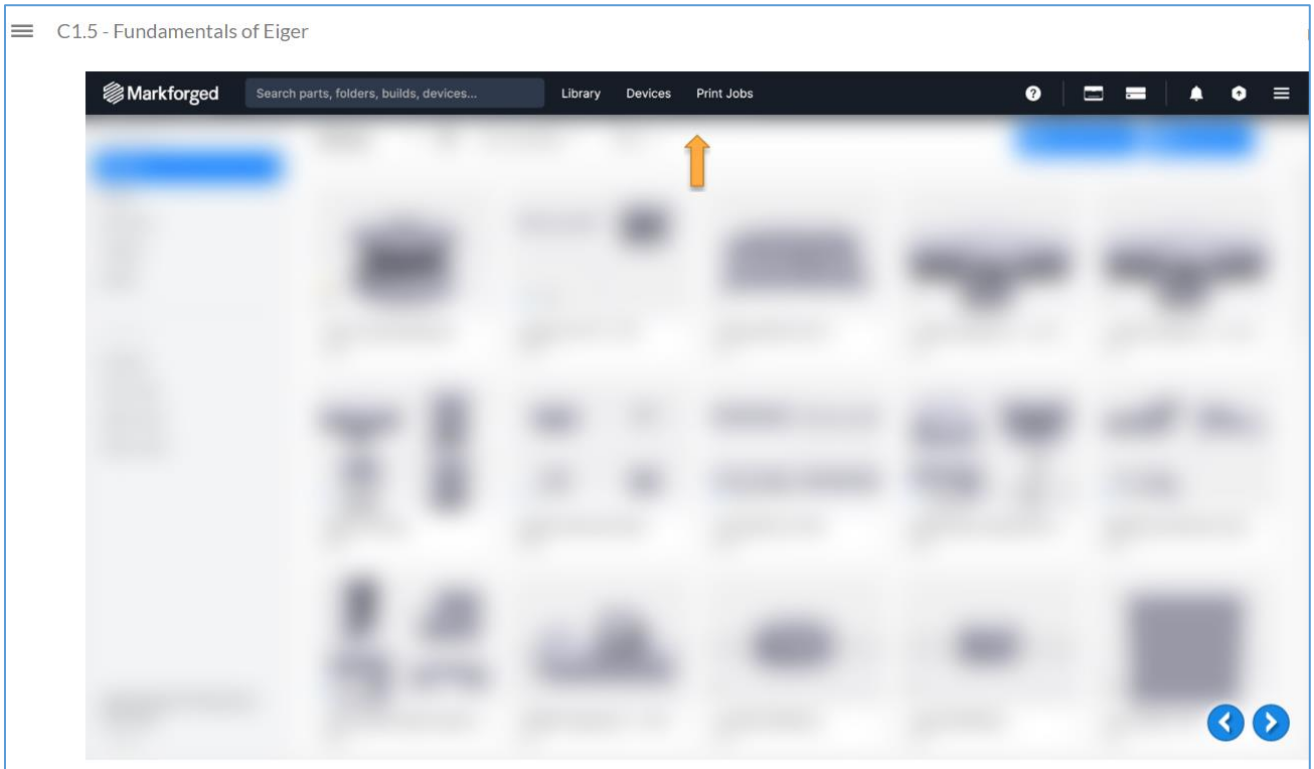


- Companies who subscribe (geabonneerd) has two extra levels to control their organization:
  - Teams.
  - Device Groups. Apparaten.

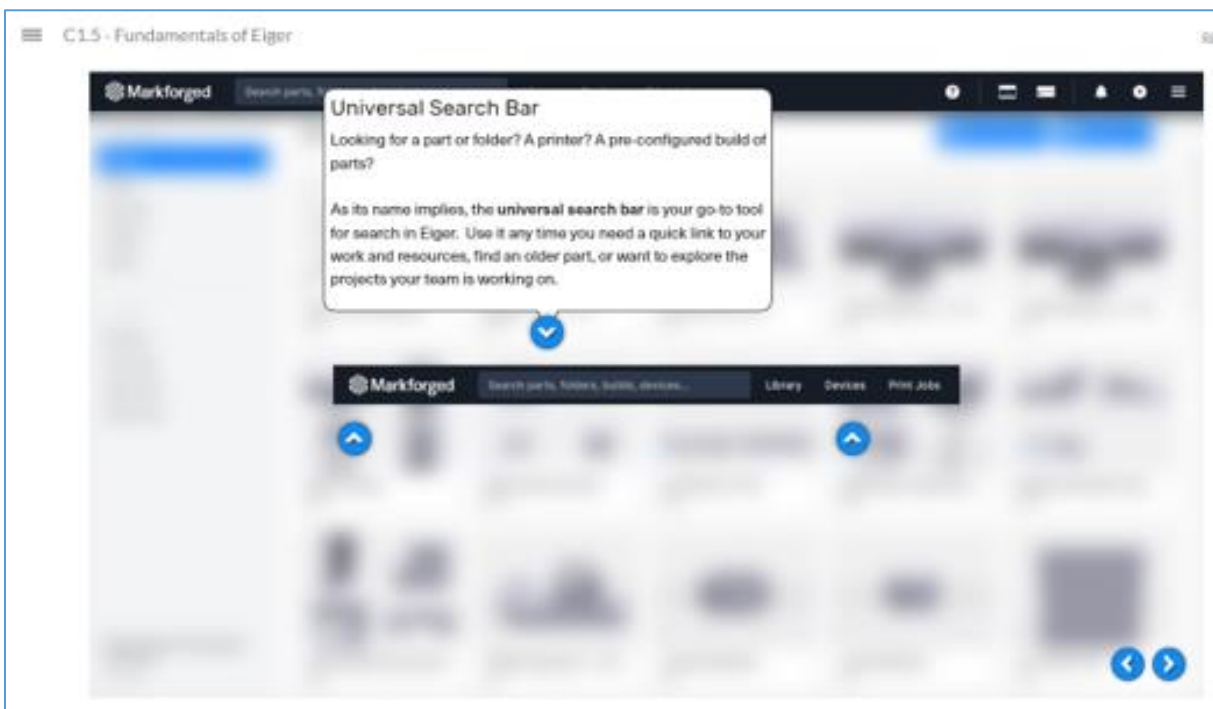


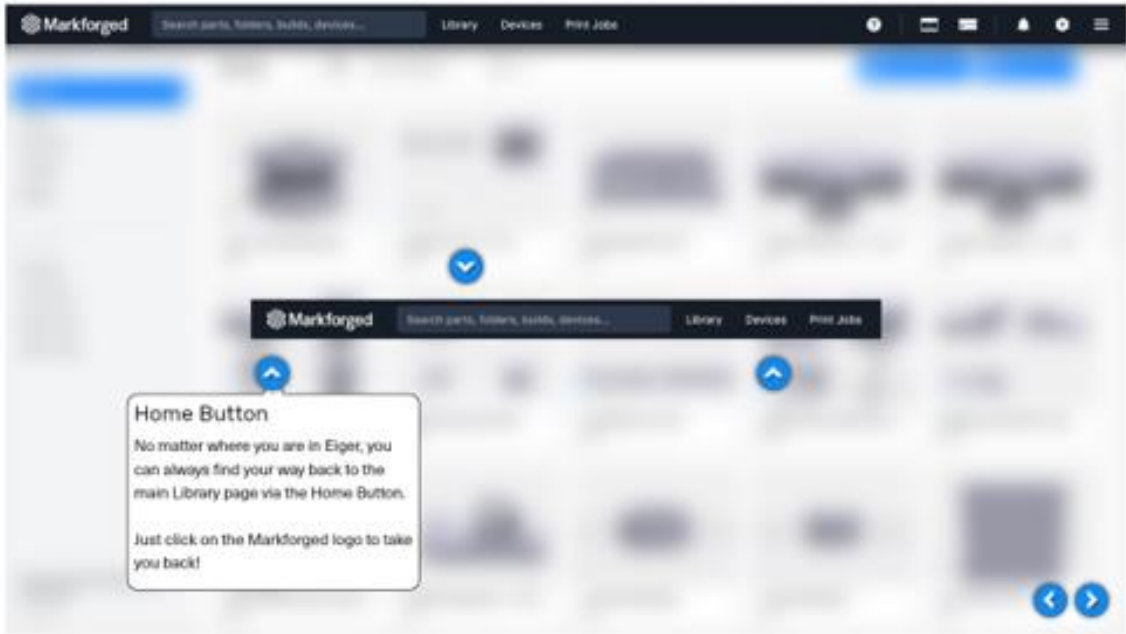
- Navigating the Home Screen.

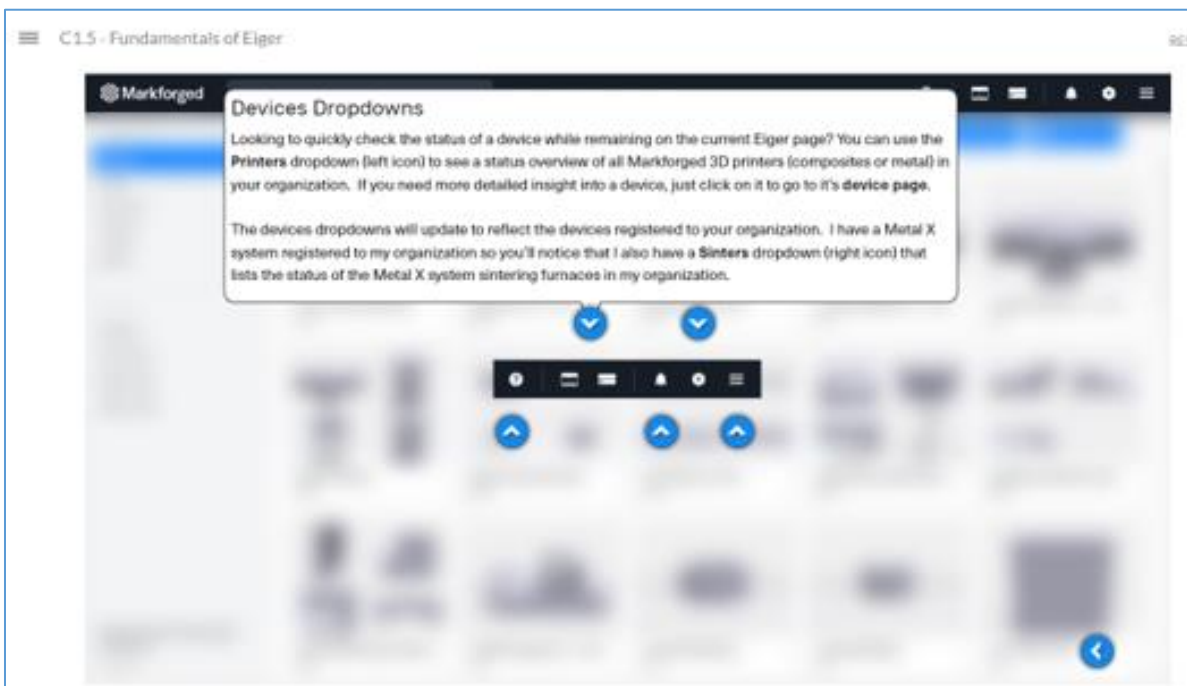
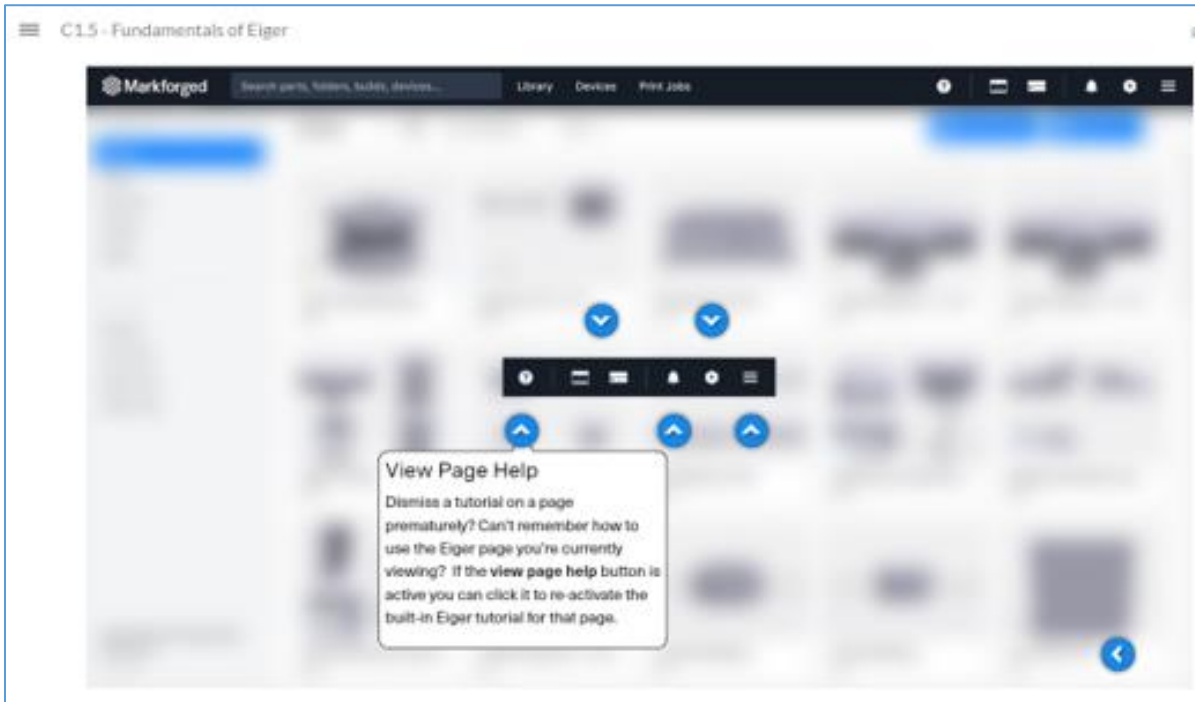


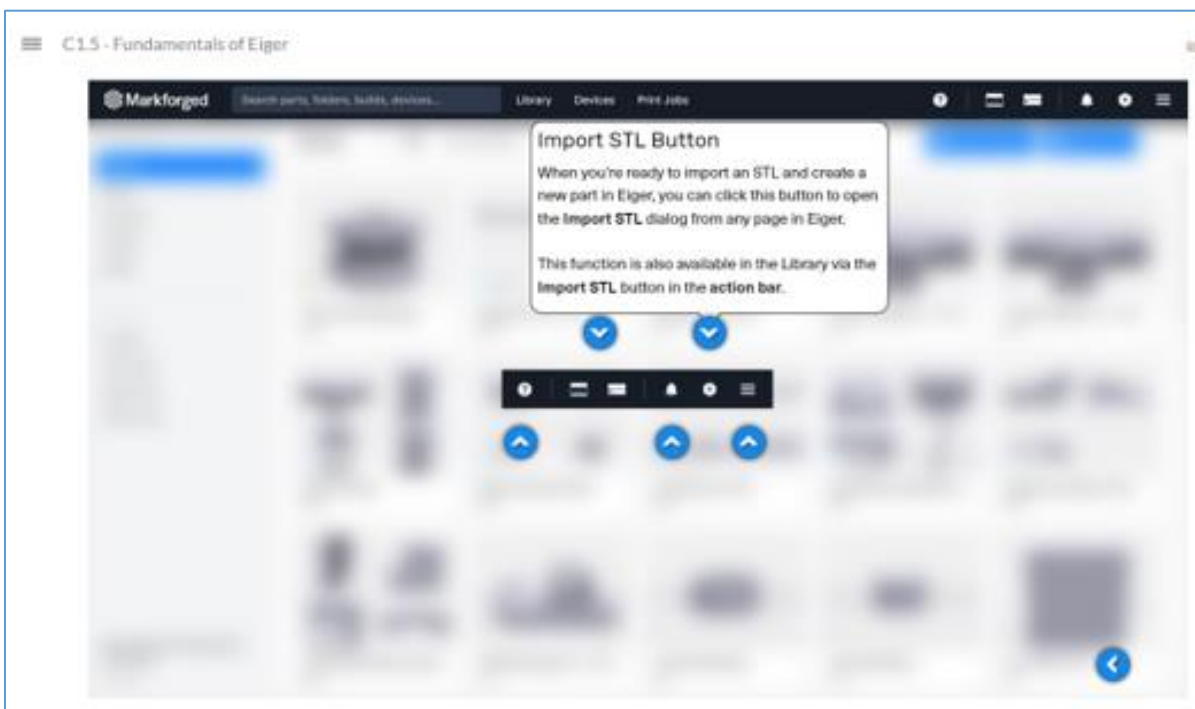
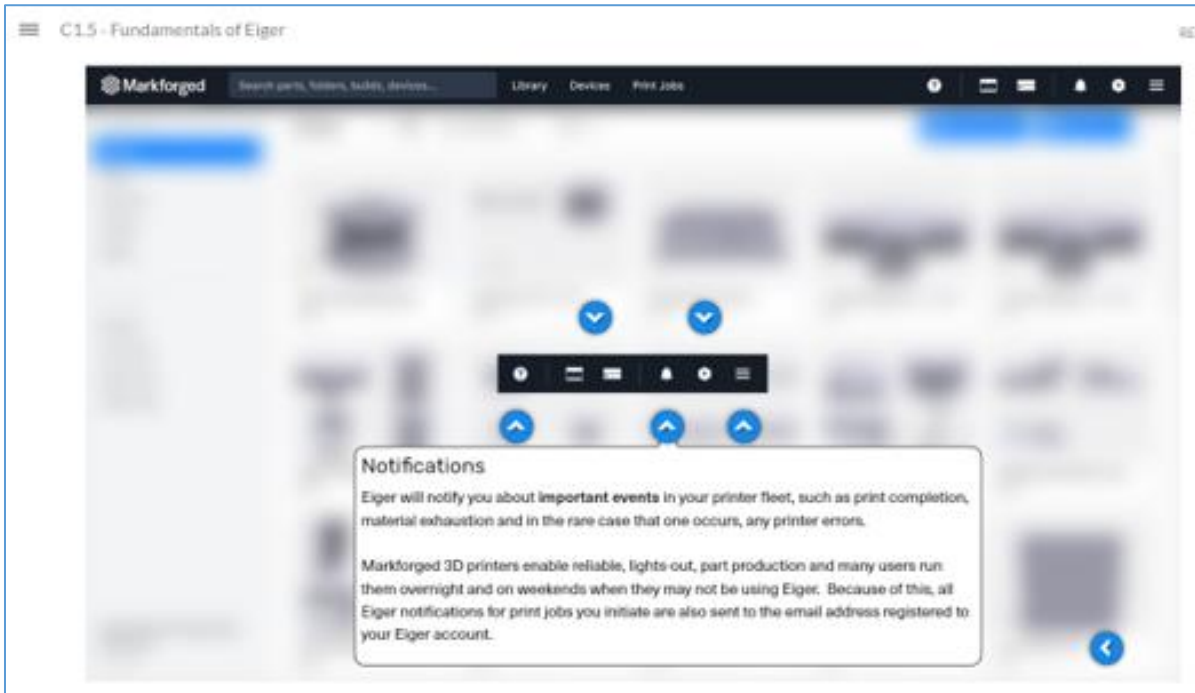


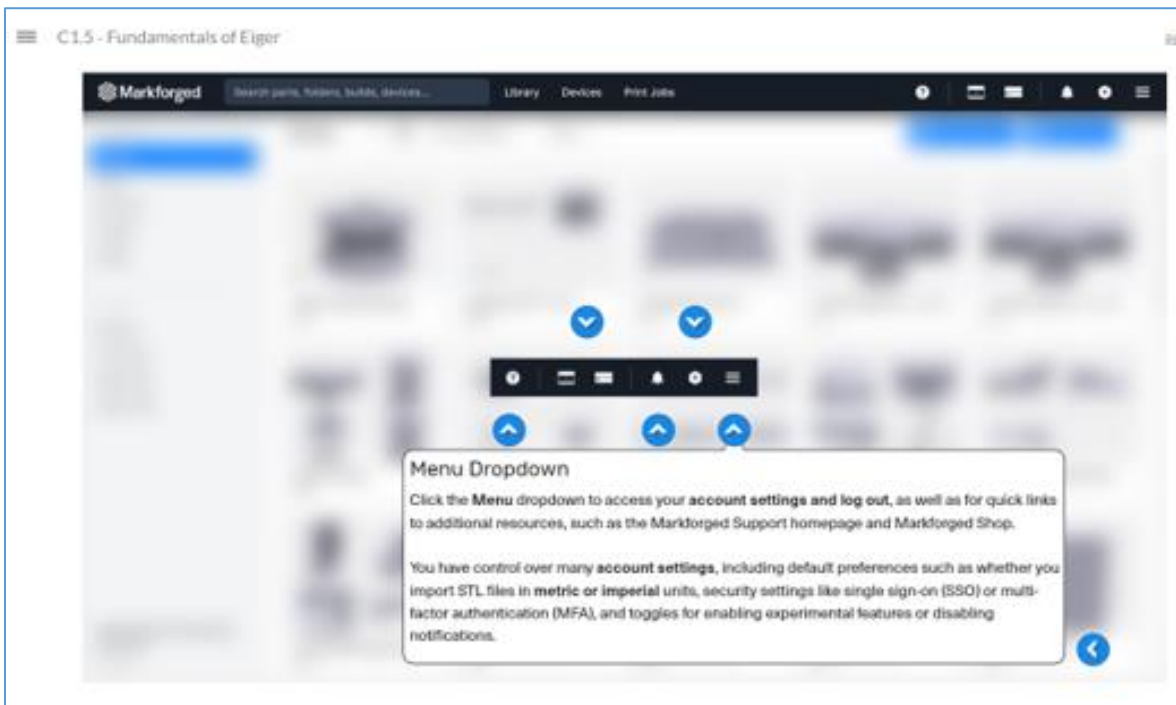
- In-depth with the Nav Bar.



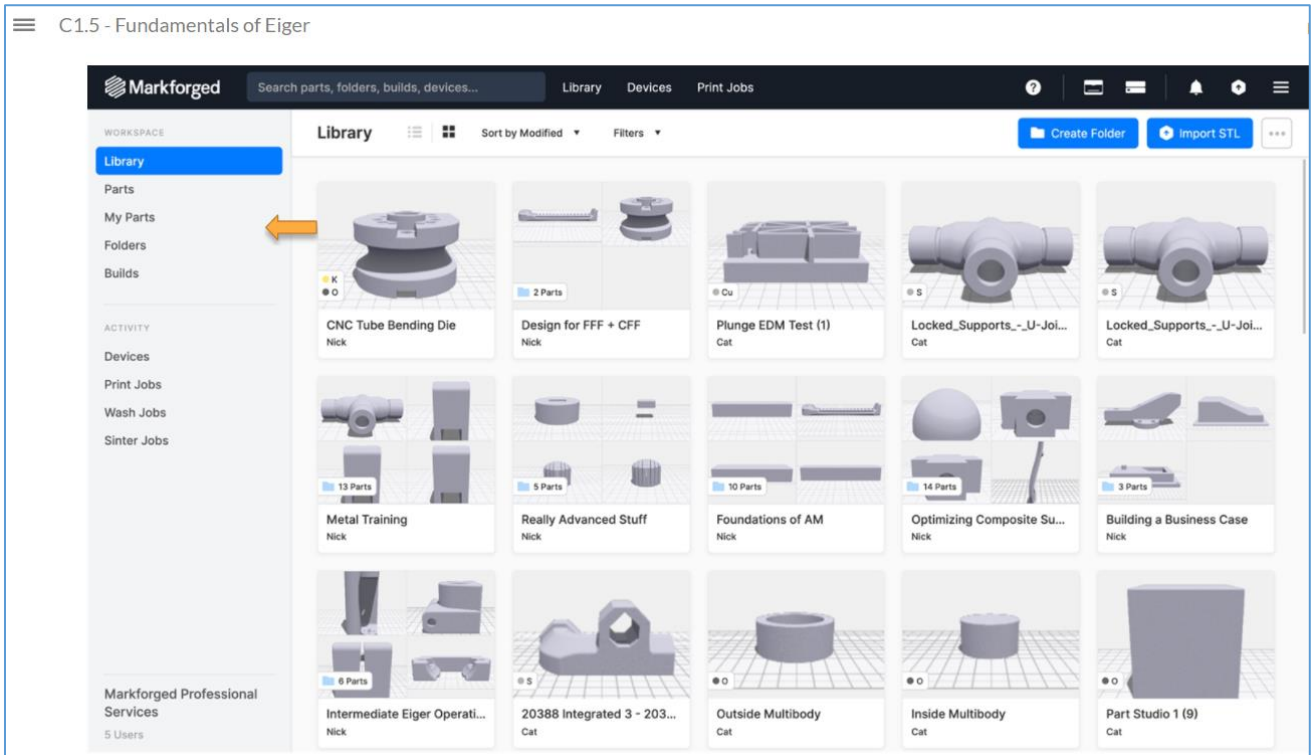




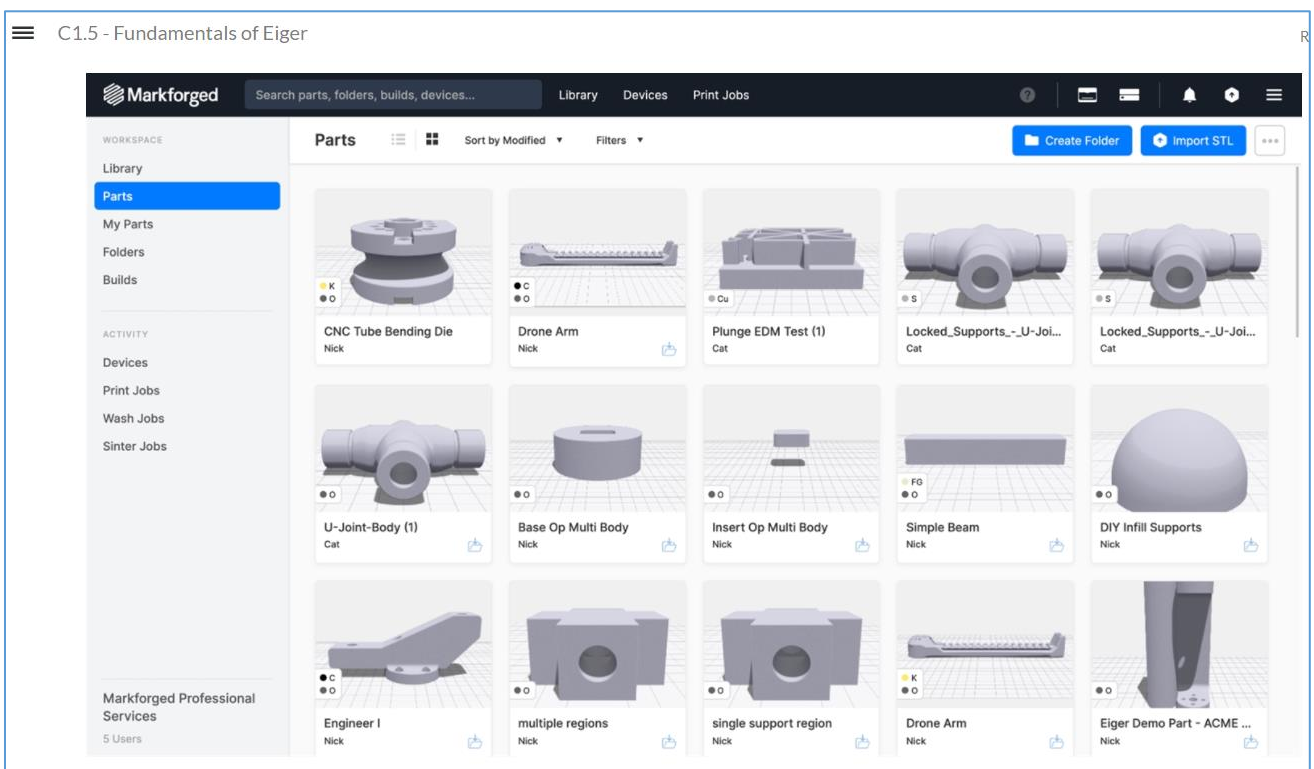




- **Additional resources: Aanvullende middelen.**

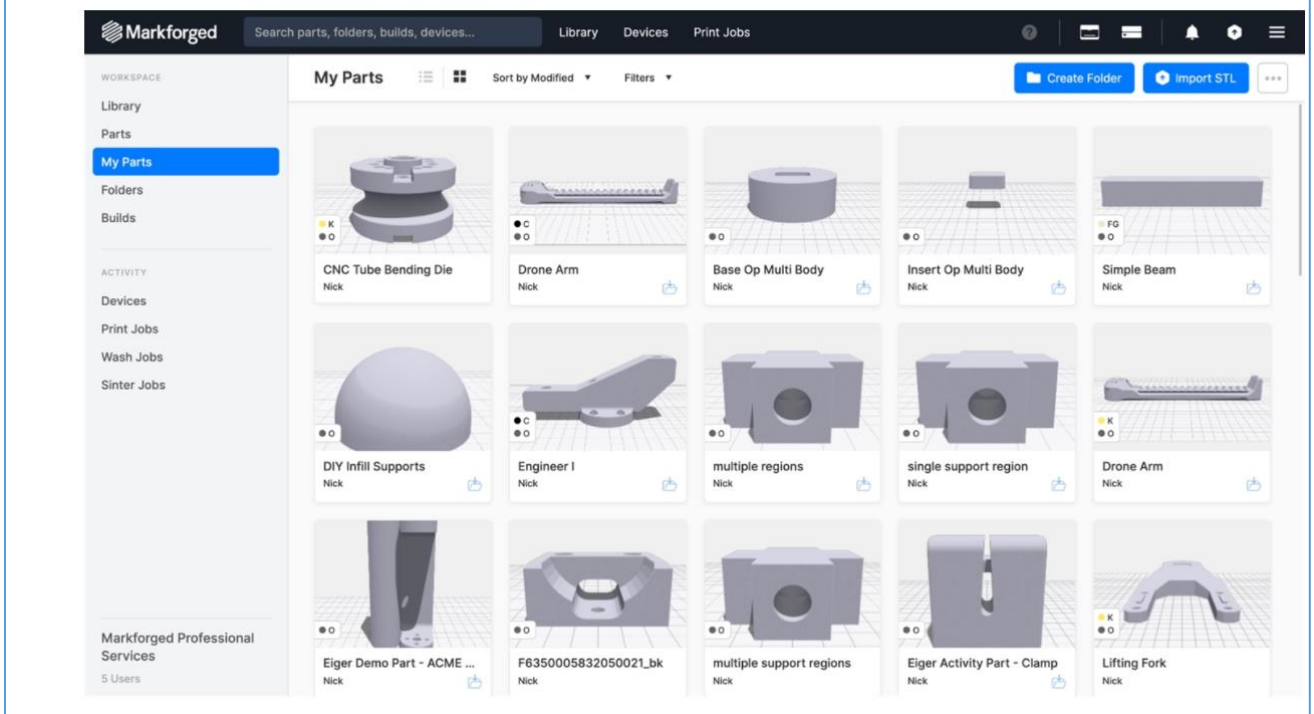


- Exploring the Library with Workspace Views.

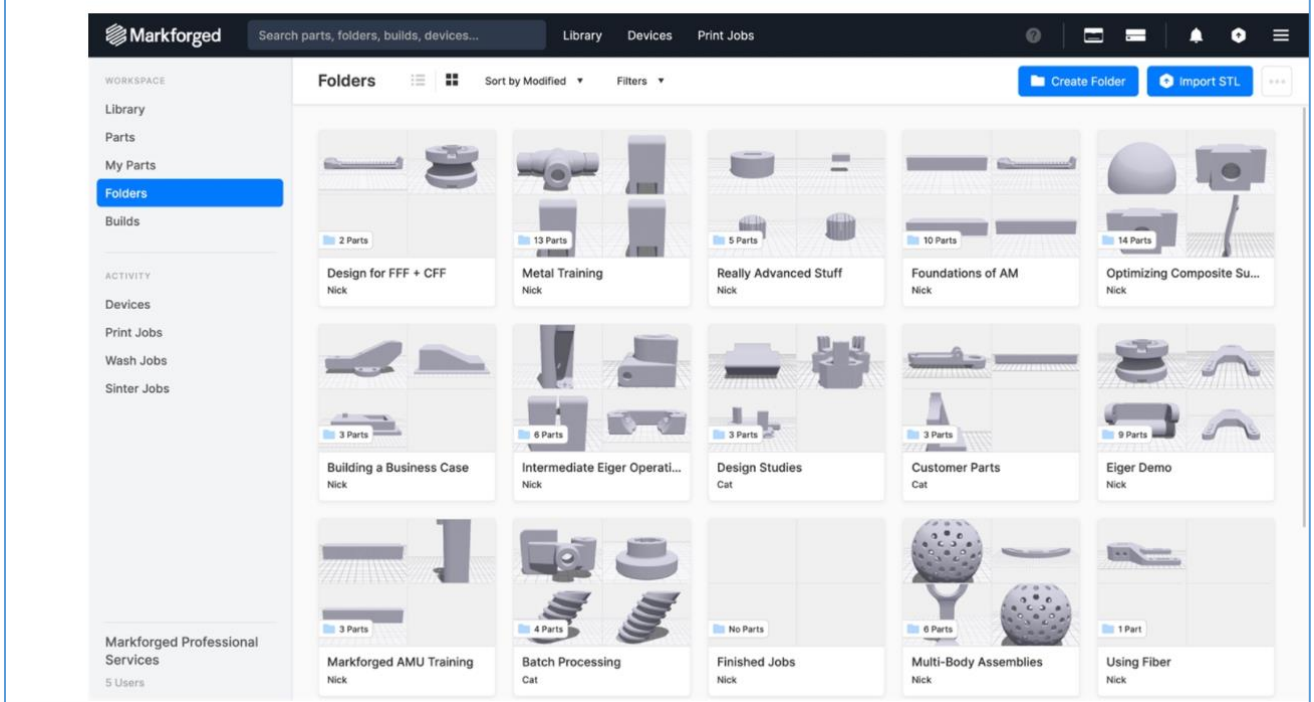


- Parts

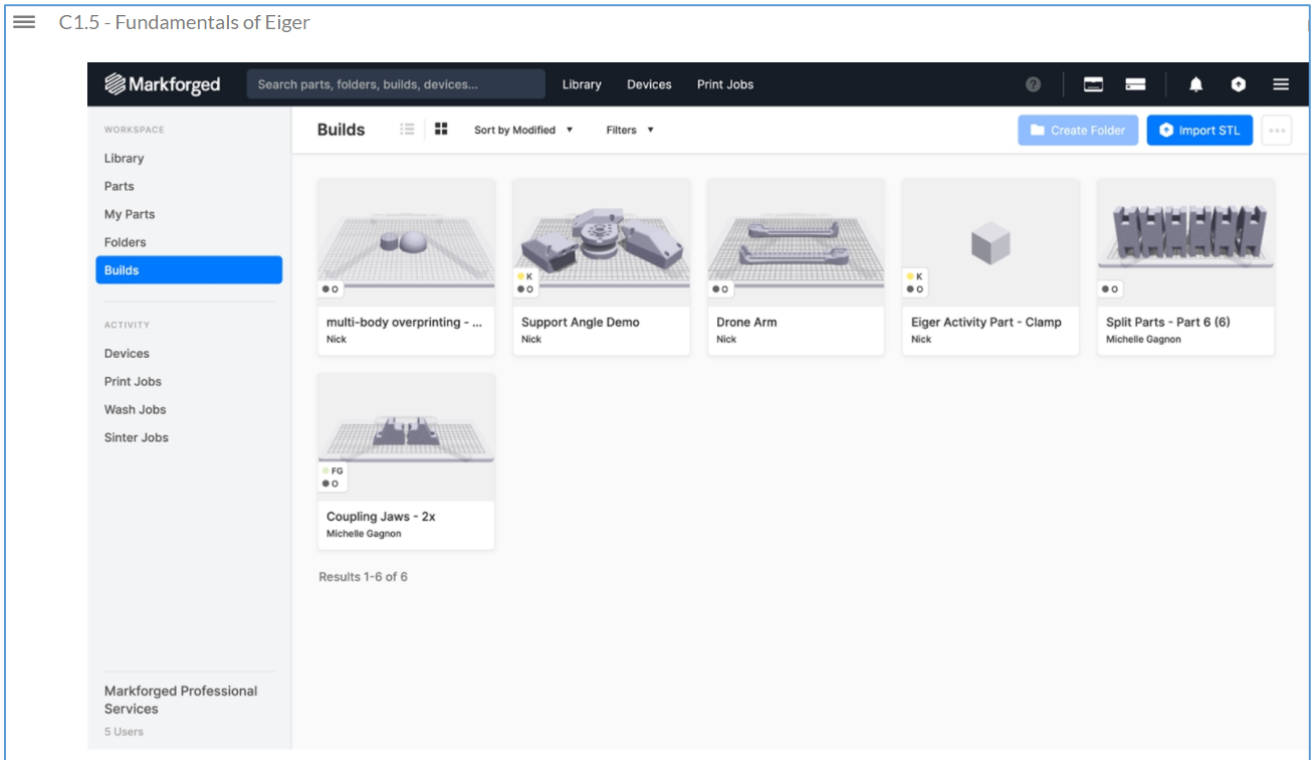




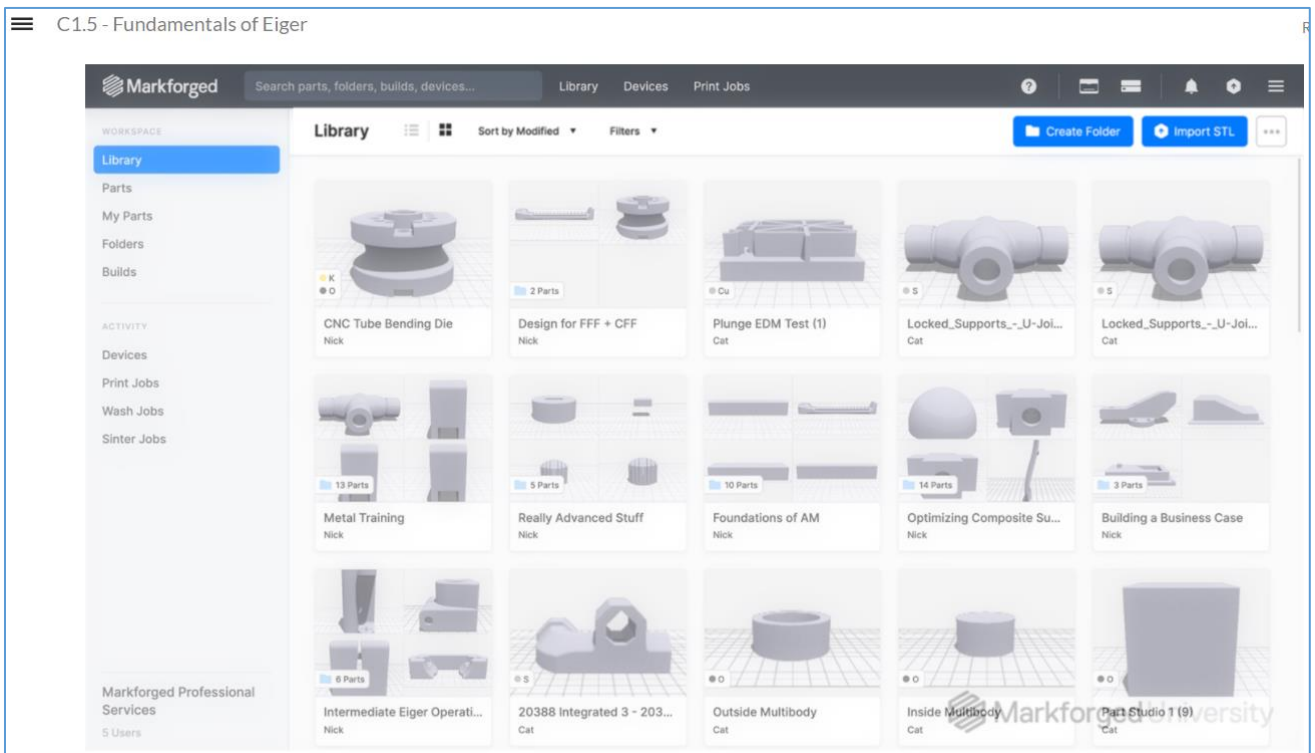
- My Parts



- Folders

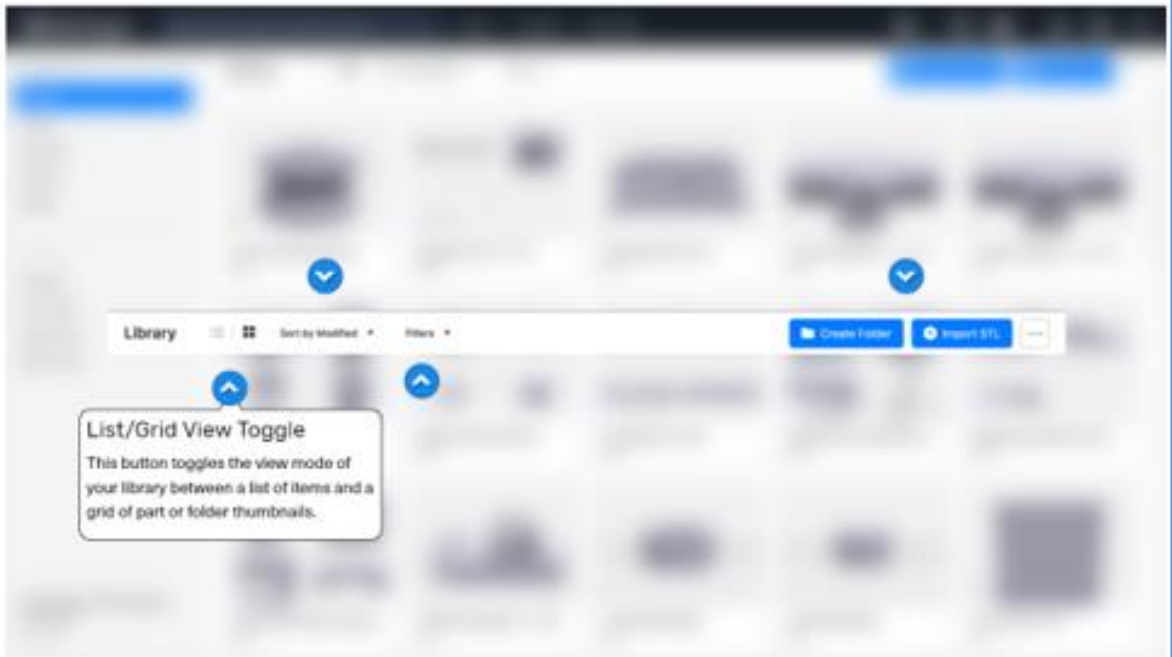
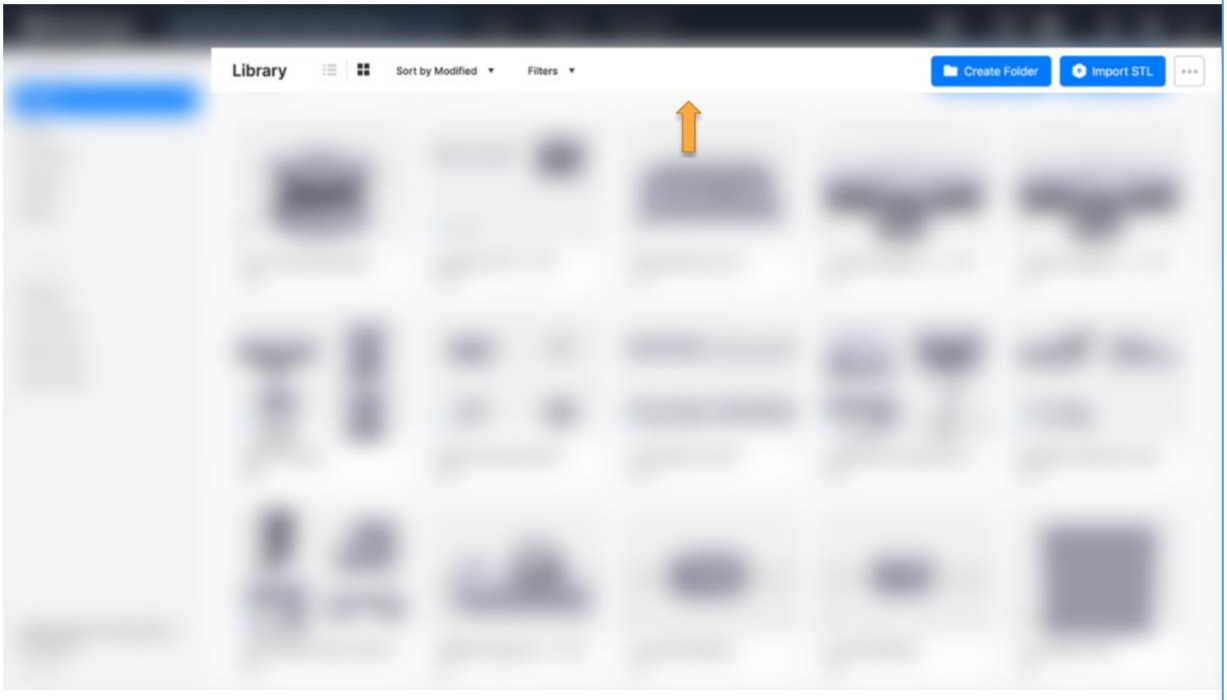


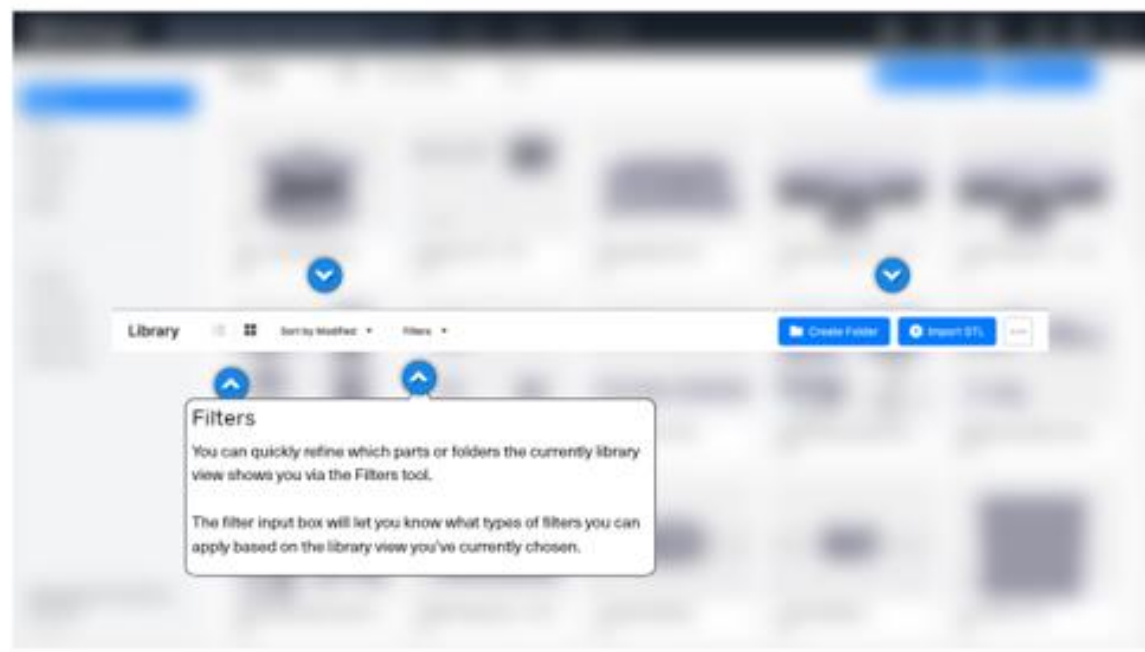
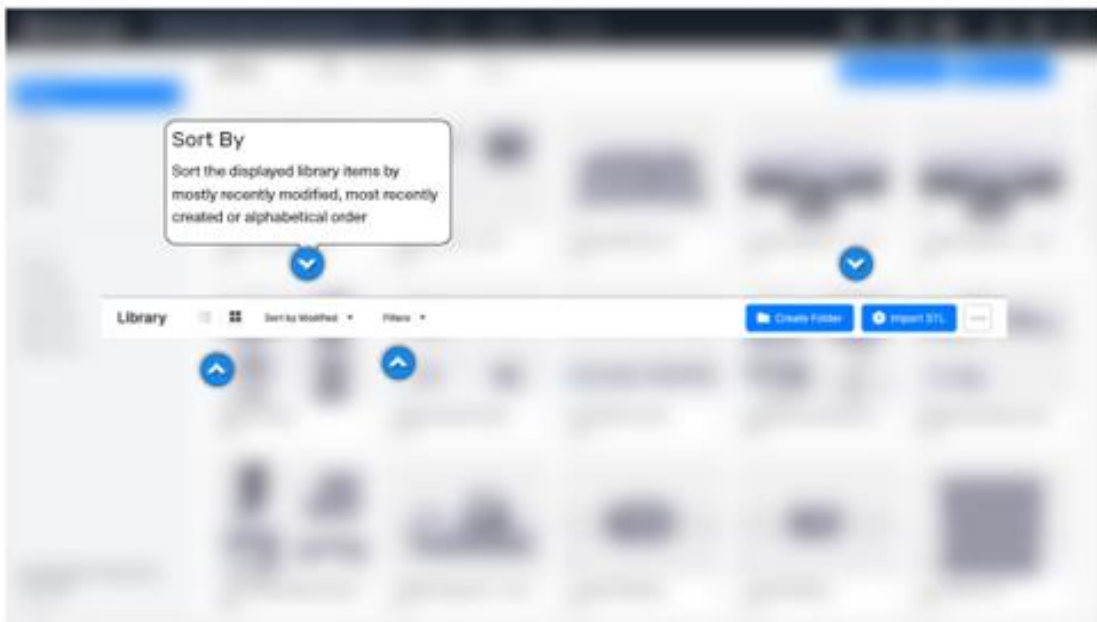
- Builds

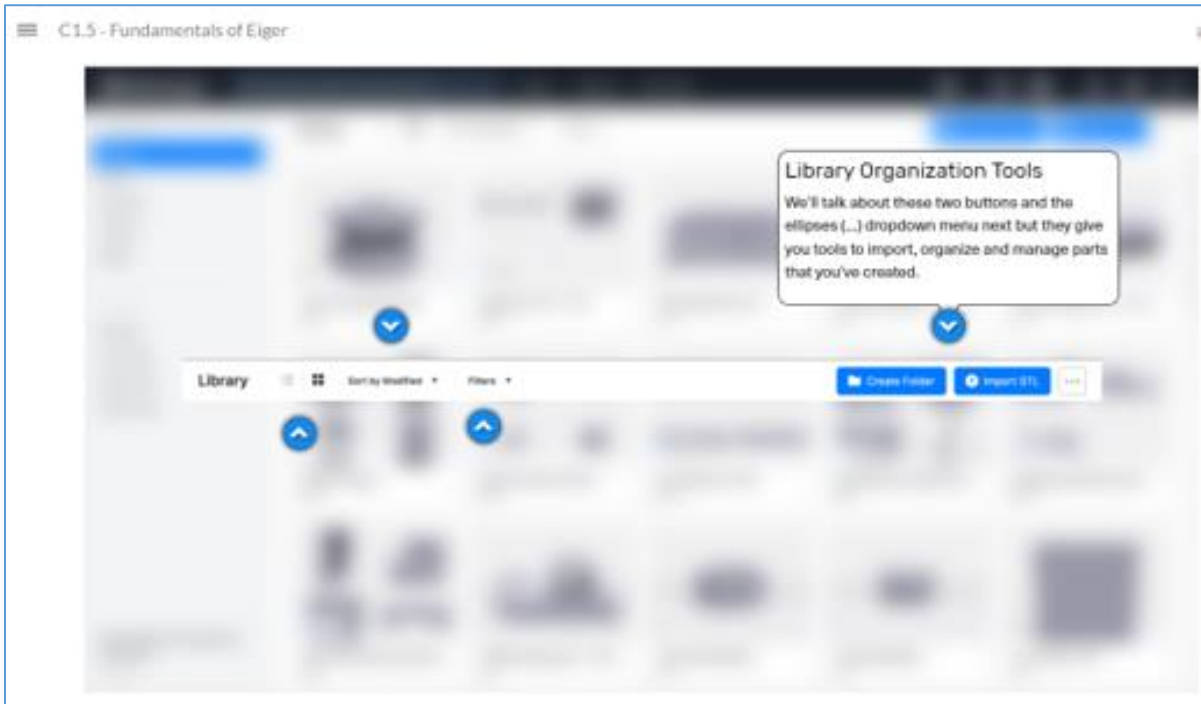


- Take control with the Action Bar

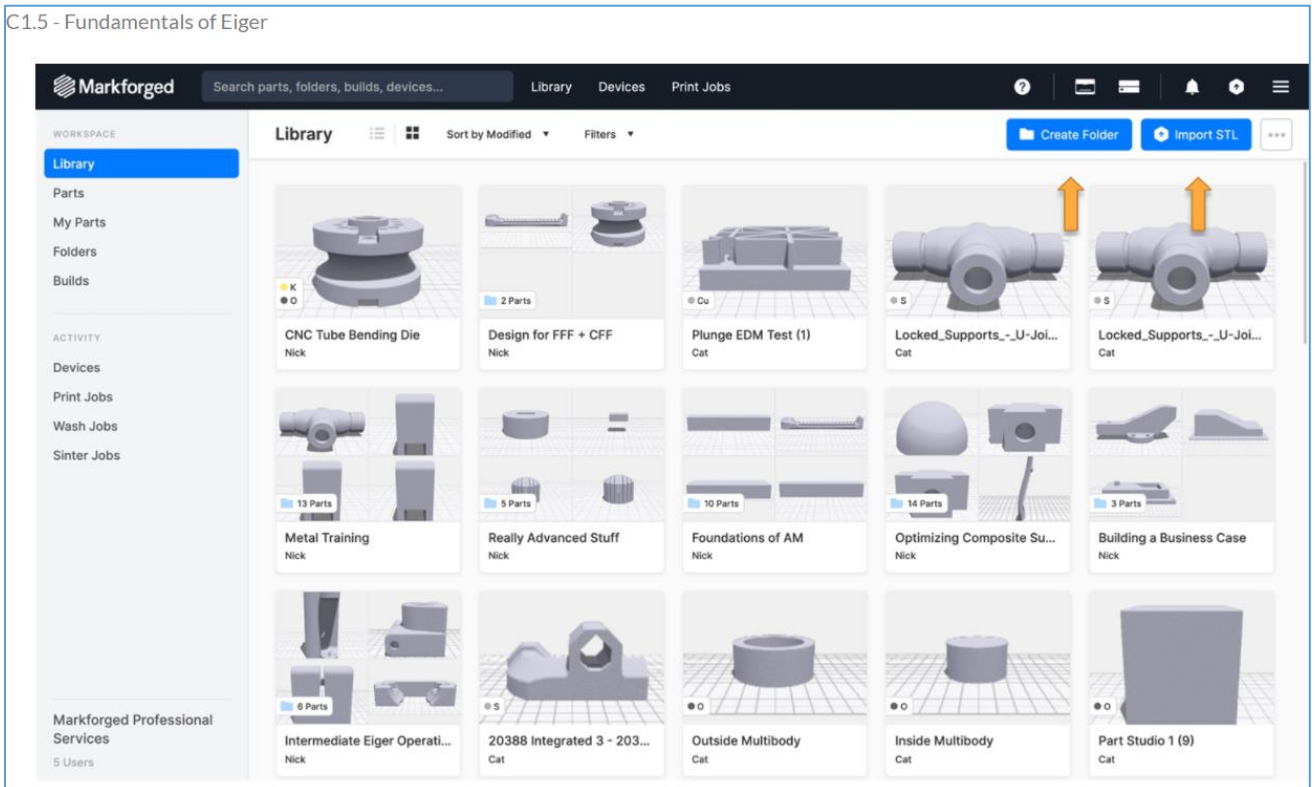




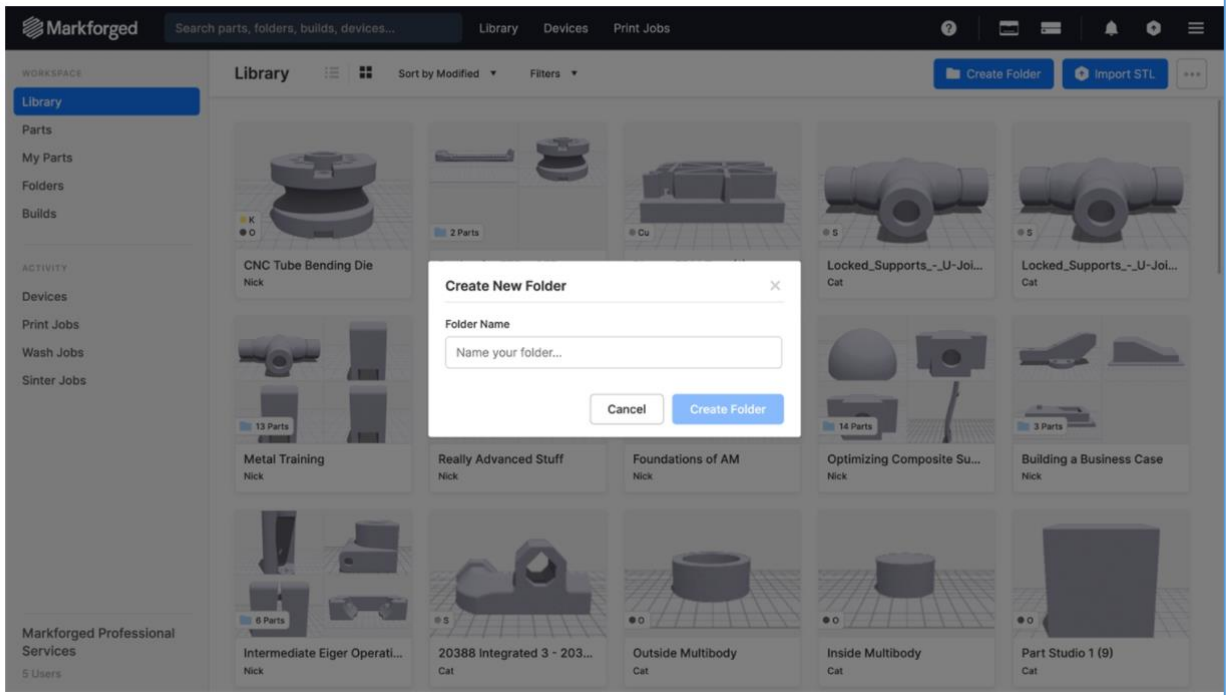




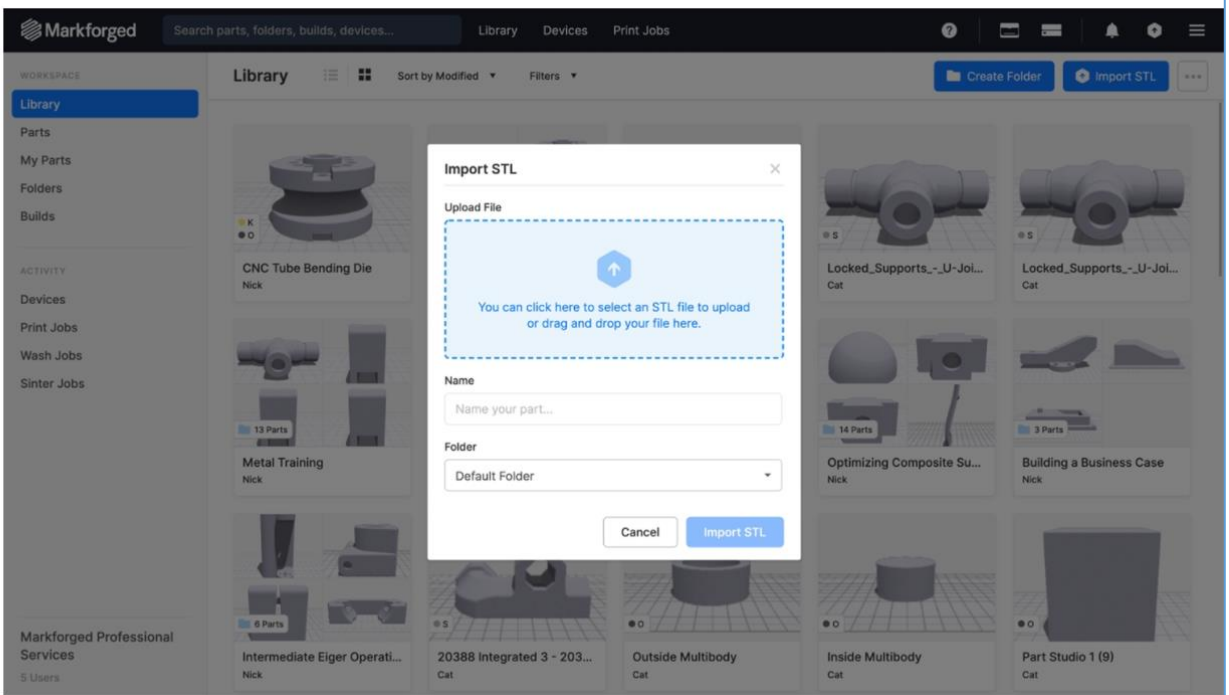
C1.5 - Fundamentals of Eiger



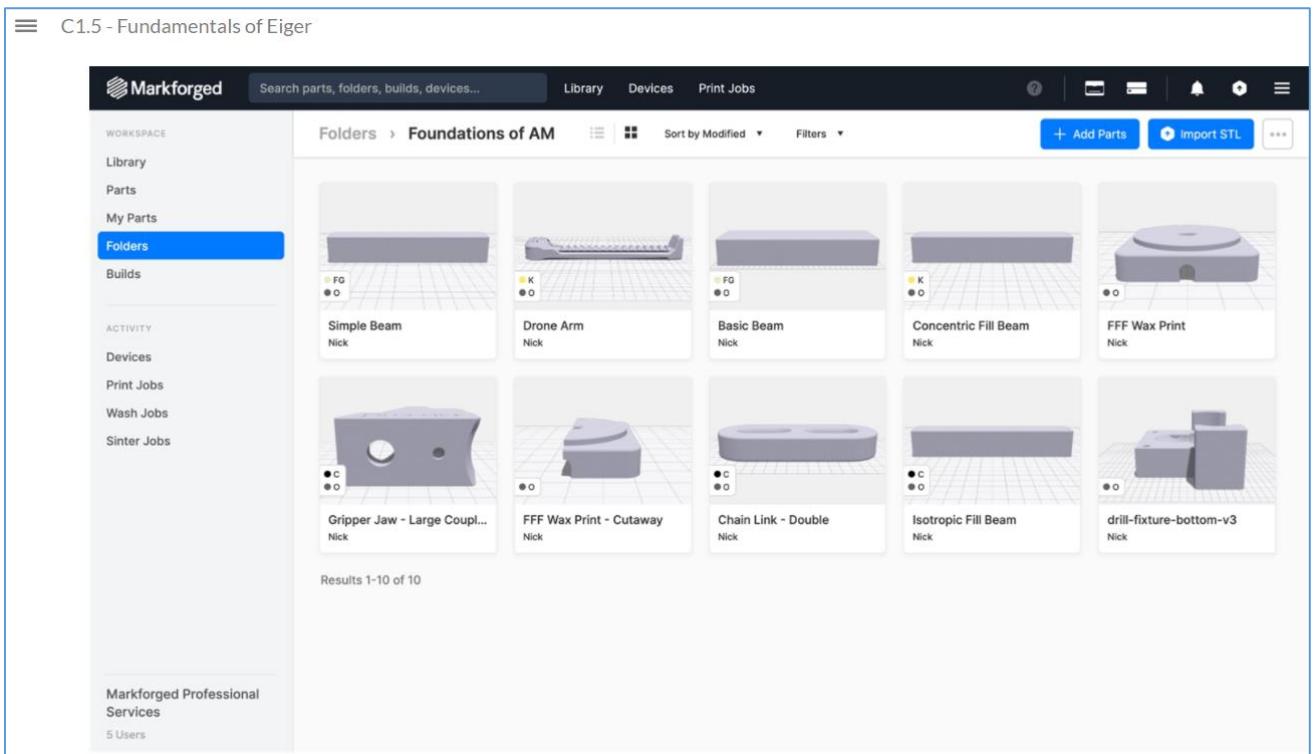
- Keeping Organized in the Library



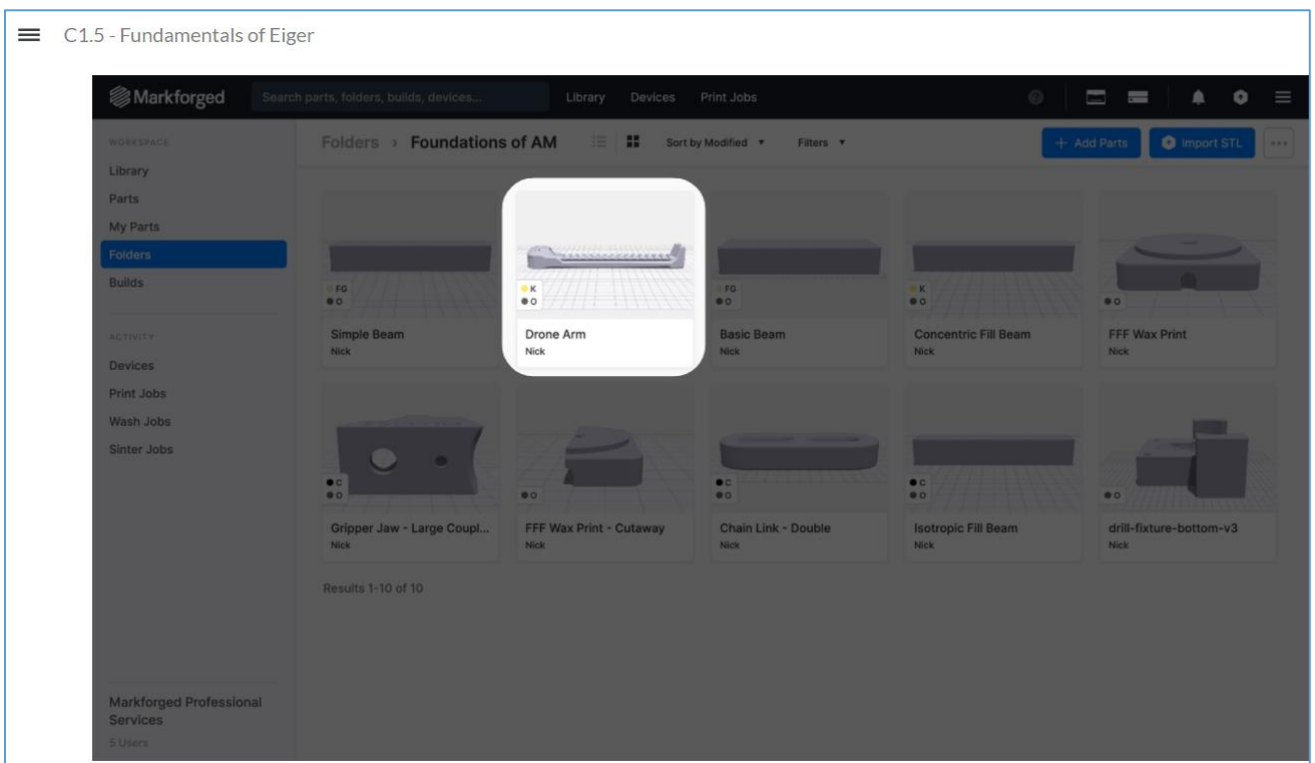
- Create folder



- Import STL

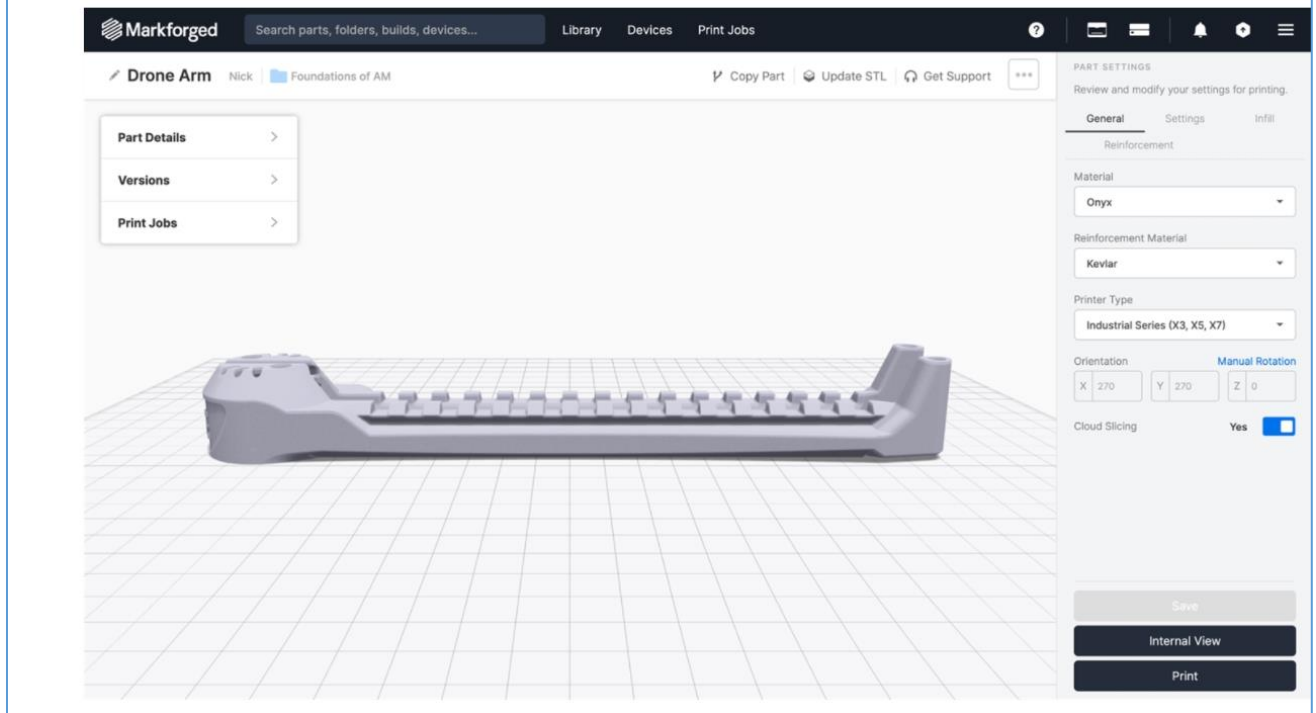


- **The Part Editor Page**

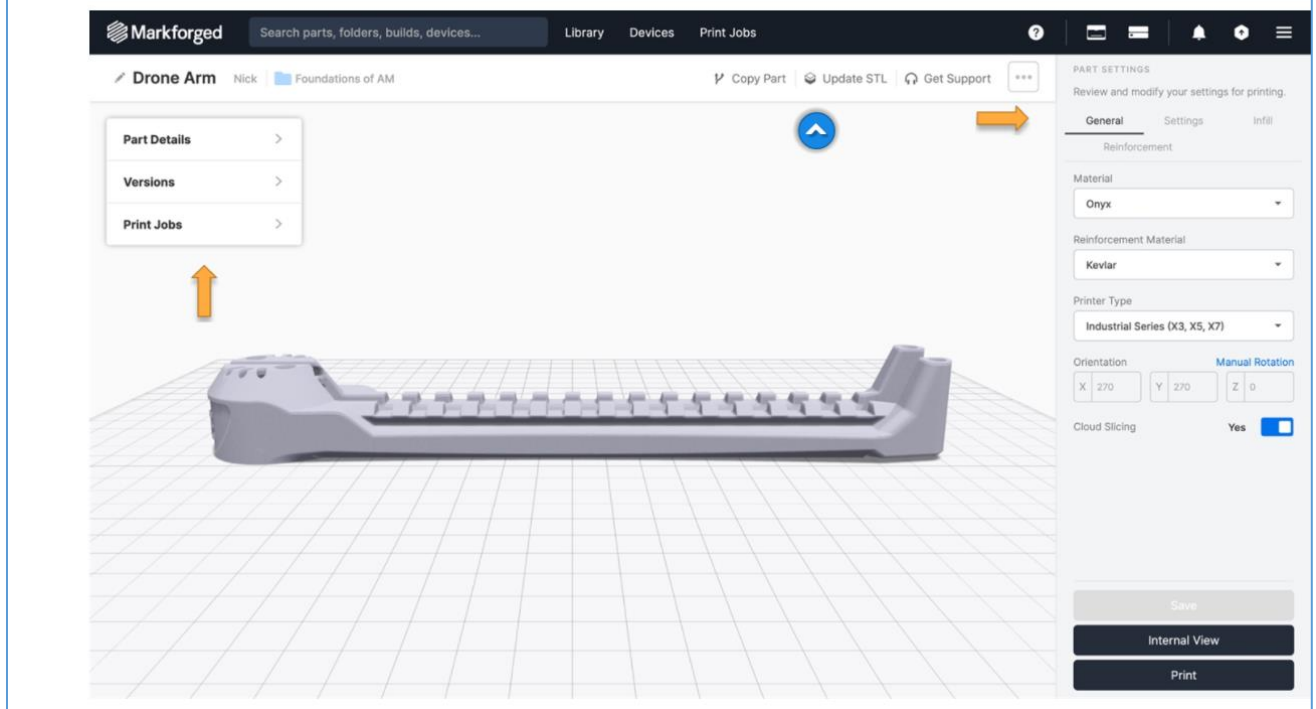


- Click on a Part (see highlighted)

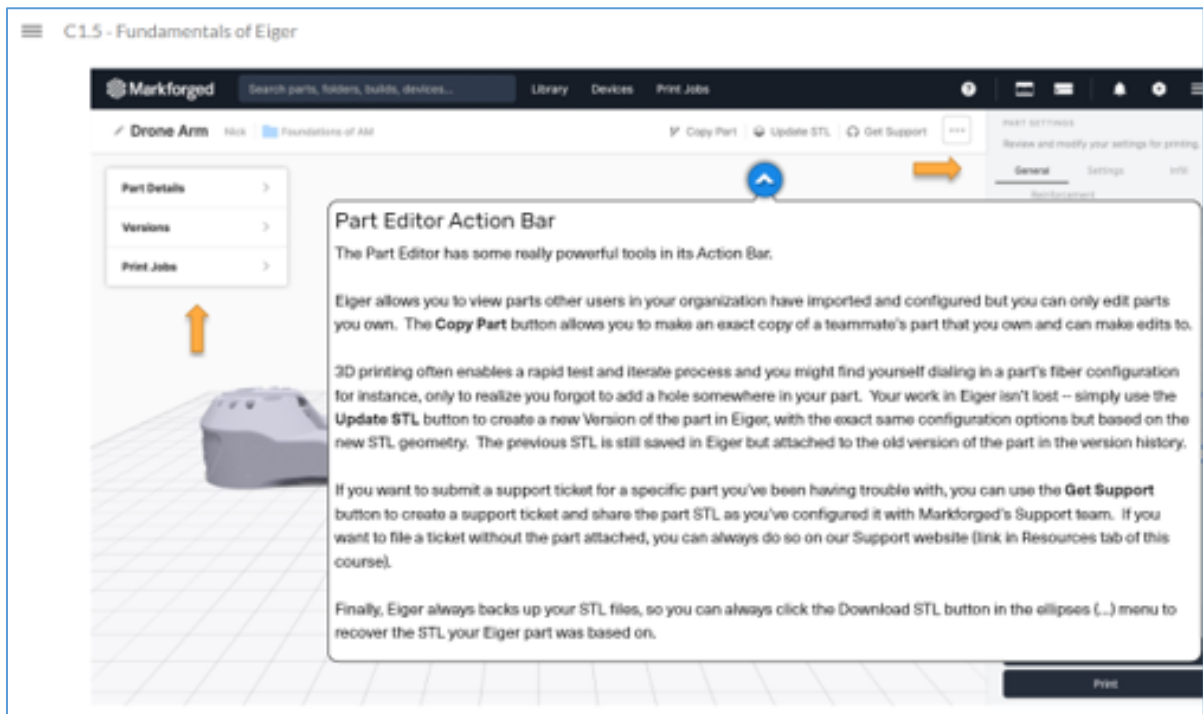
C1.5 - Fundamentals of Eiger



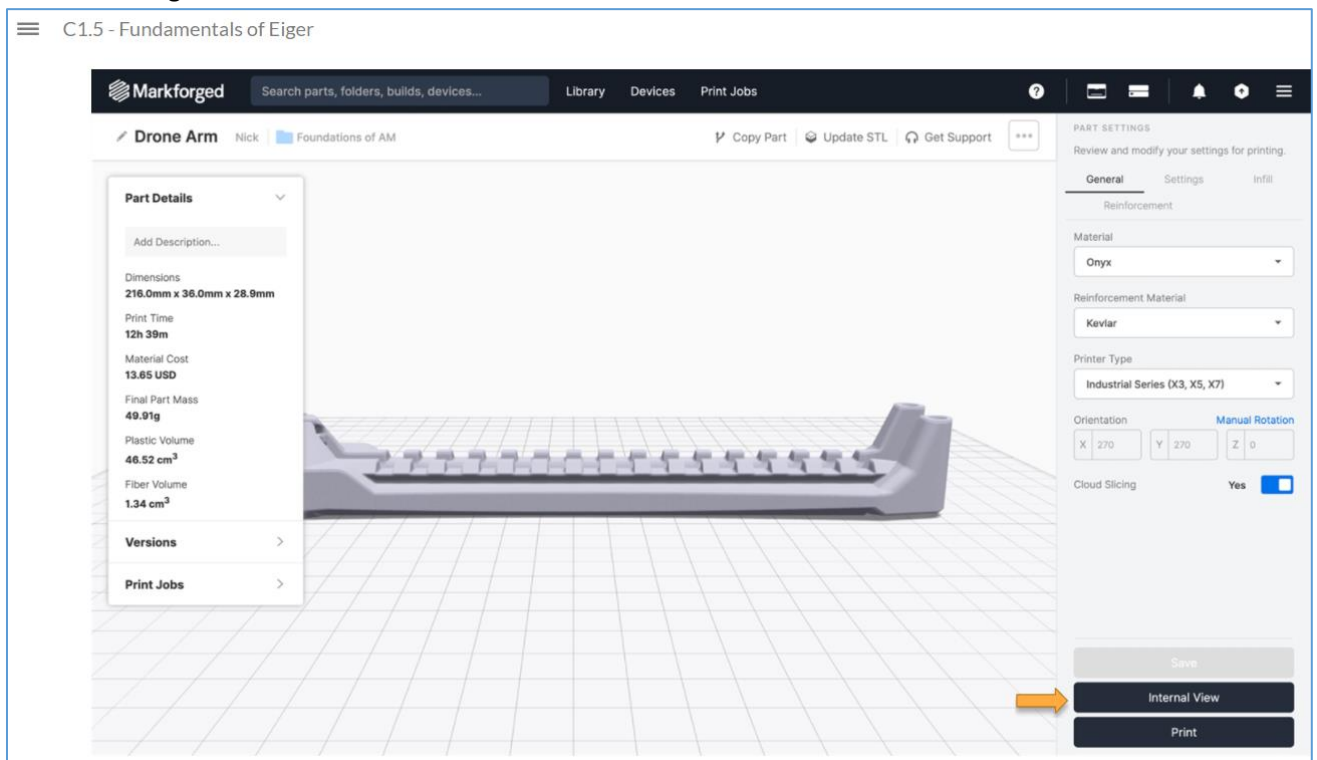
C1.5 - Fundamentals of Eiger



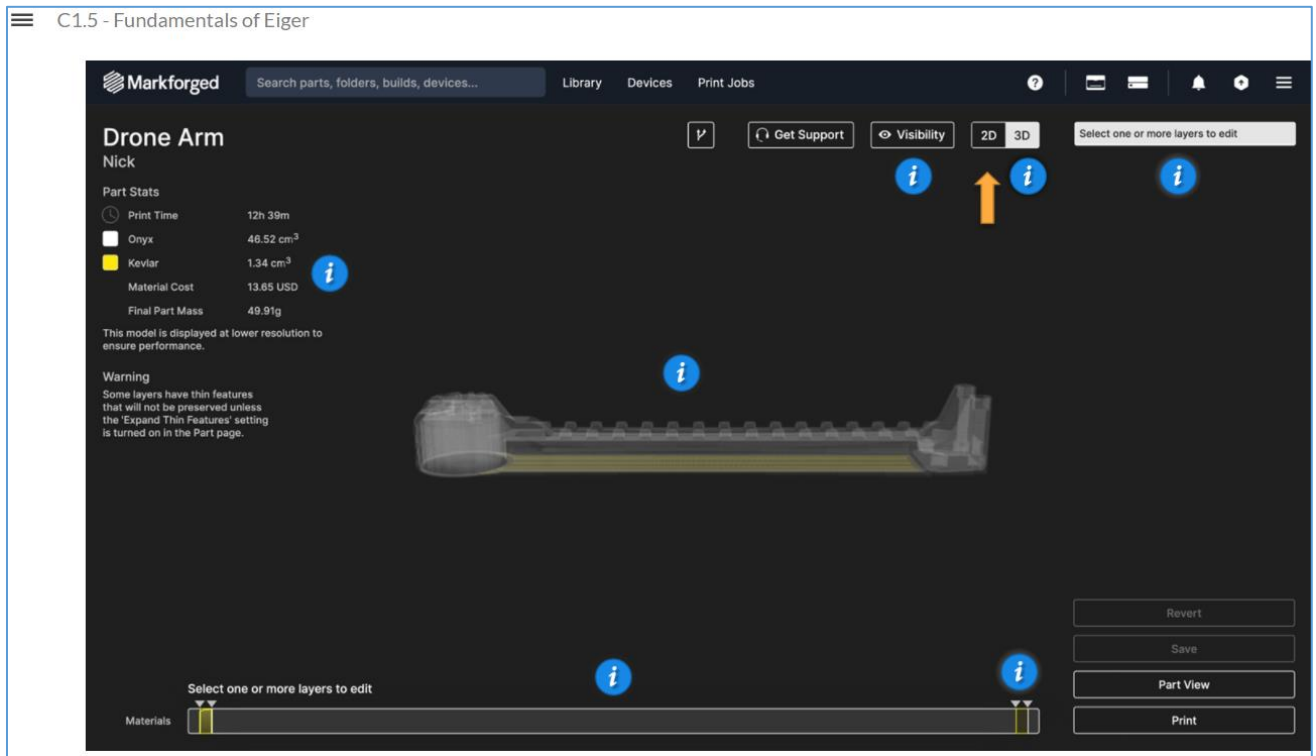




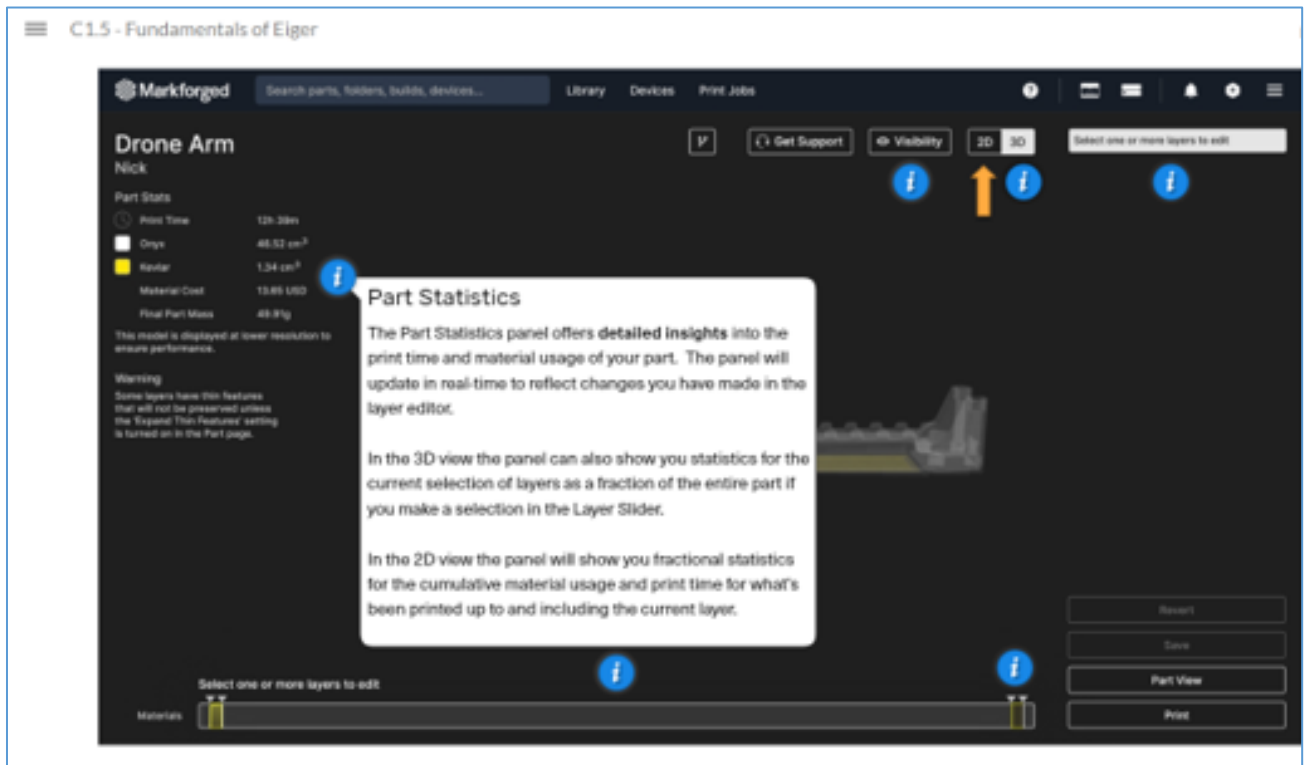
- Iterate = herhalen.
- Dialing = kiezen.



- The Layer Editor: 2D and 3D views



- Internal View





C1.5 - Fundamentals of Elger

Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

### Drone Arm

Nick

Part Stats

Print Time	12h 38m
Days	49.52 cm <sup>3</sup>
Volume	1.24 cm <sup>3</sup>
Material Cost	15.60 USD
Final Part Mass	49.71g

This model is displayed at lower resolution to ensure performance.

Warning

Some layers have 3D features that will not be processed unless the "Expanded Thin Features" setting is turned on in the Part page.

Get Support Visibility 2D 3D Select one or more layers to edit

#### Layer Slider

The layer slider is a navigational tool for selecting or traversing the layers of the sliced part, as well as an infographic about the reinforcement fiber distribution in the part.

The slider aligns the layers of the part from left to right, with the first layer or bottom of the part represented at the left-most end of the slider and the last layer or top of the part at the right-most end of the slider.

We'll discuss the Layer Slider in more detail next but for now, you should know that you can either click on the slider or click-and-drag on it, for two different effects. You can click the slider to view an existing group (in the 3D view) or layer (in the 2D view). If you click-and-drag on the Layer Slider it will make a new selection of layers in the 3D view and scroll through a series of individual layers in the 2D view.

Select one or more layers to edit

Materials

Reset Save Part View Print

C1.5 - Fundamentals of Elger

Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

### Drone Arm

Nick

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Get Support Visibility 2D 3D Select one or more layers to edit

#### Part 3D Internal View

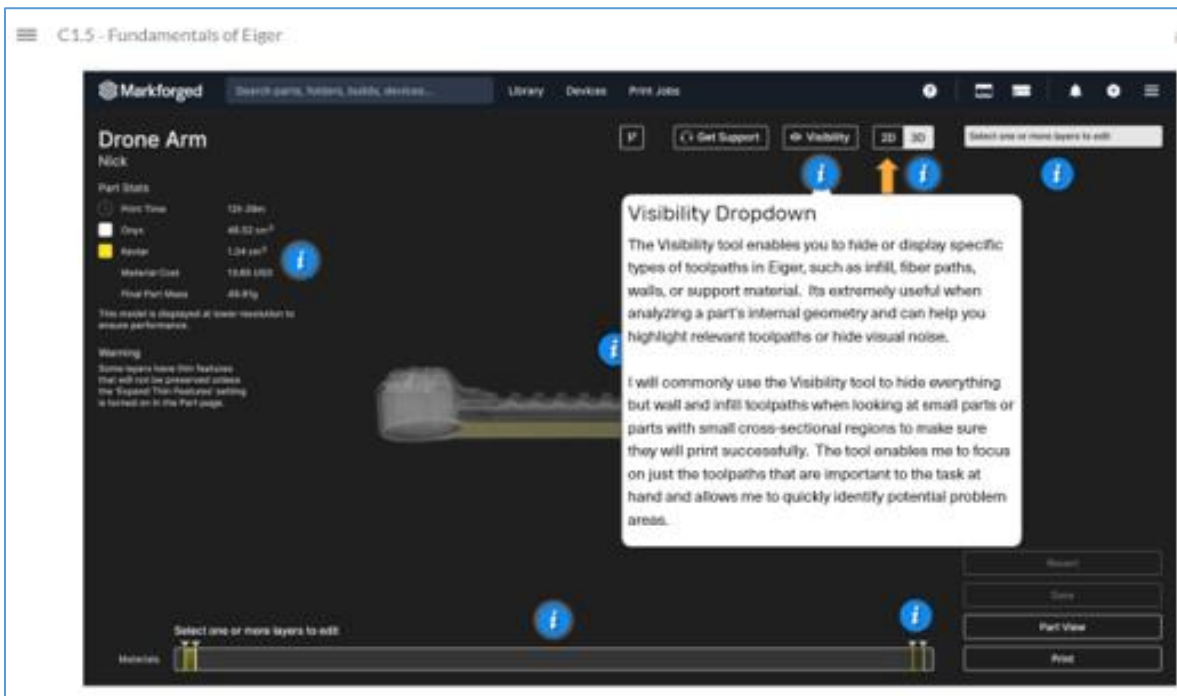
This is the 3D internal view of the drone arm we've been discussing. You'll notice immediately that it has a semi-transparent quality, kind of like an X-ray. This enables you to see the full geometry of the part (including internal regions that could be otherwise hidden from view) and identify where reinforcement fiber has been laid down.

The 3D internal view also makes it possible to visualize the structural layout of fiber in your part. We'll discuss this later but many times where fiber is placed is much more important than how much has been added.

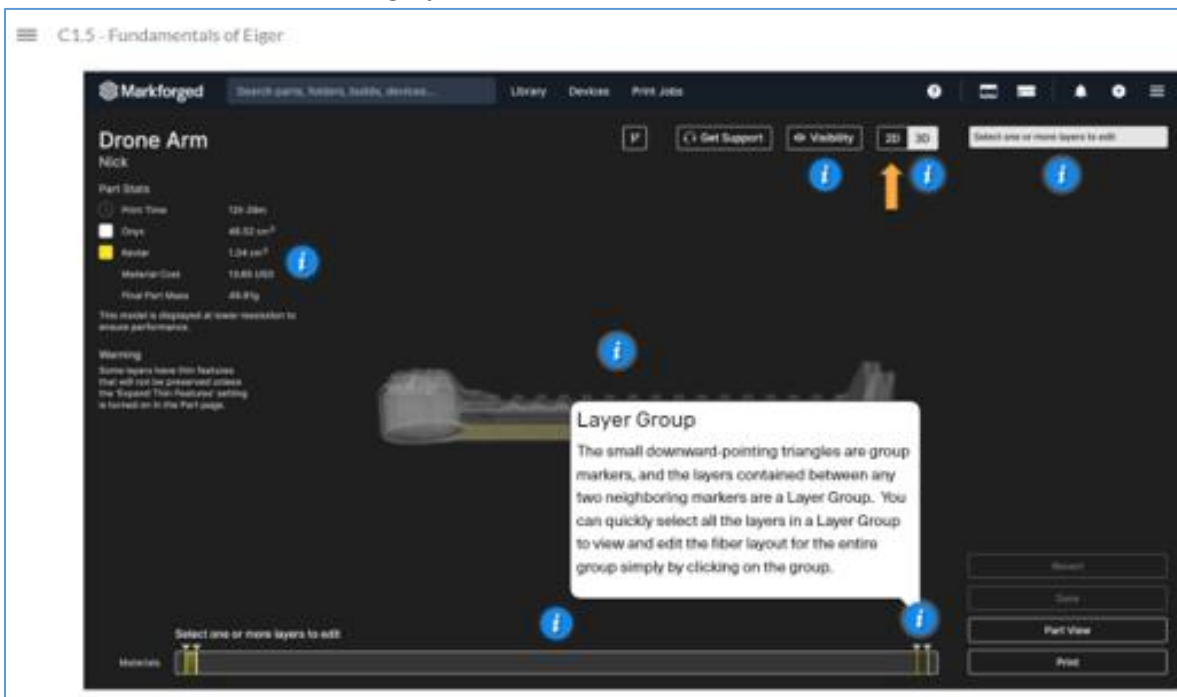
Select one or more layers to edit

Materials

Reset Save Part View Print



- Enables = Maakt het mogelijk...



**2D/3D View Selector**

This tool allows you to switch between the 2D and 3D views in the Layer Editor.

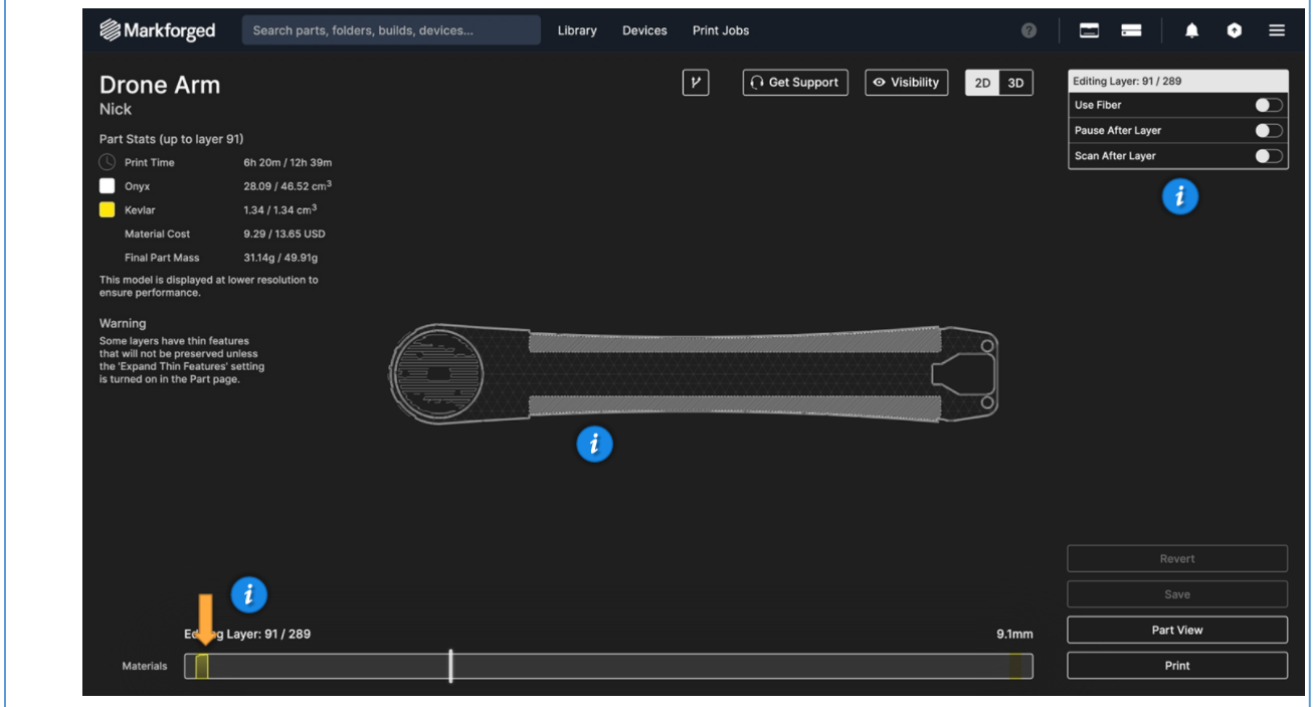
The 3D view displays the part as a semi-transparent 3D model, with colored toolpaths indicating plastic or fiber reinforcement. Making a selection in the Layer Slider will highlight those layers in the 3D view.

The 2D view presents a top-down view of a single layer of the part at a time. You can choose the layer you're configuring via the Layer Slider, which only allows single layer selections when in the 2D view.

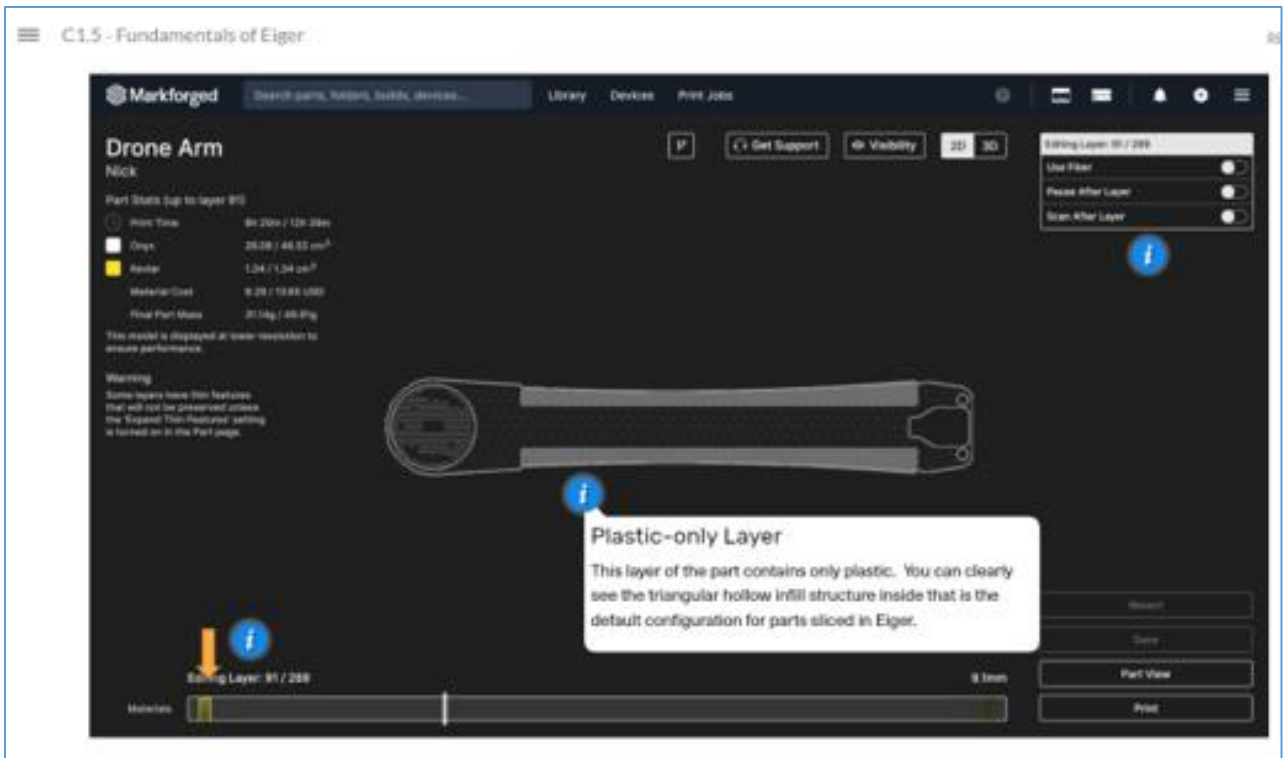
The 3D view is primarily used for bulk editing of the fiber configuration of groups of layers, while the 2D view enables precision control over individual layers.

**Group/Layer Settings**

This panel contains the fiber settings for the selected layer or layers. Try clicking on the Layer Slider to activate this panel and see what options it contains!



- 2D View.



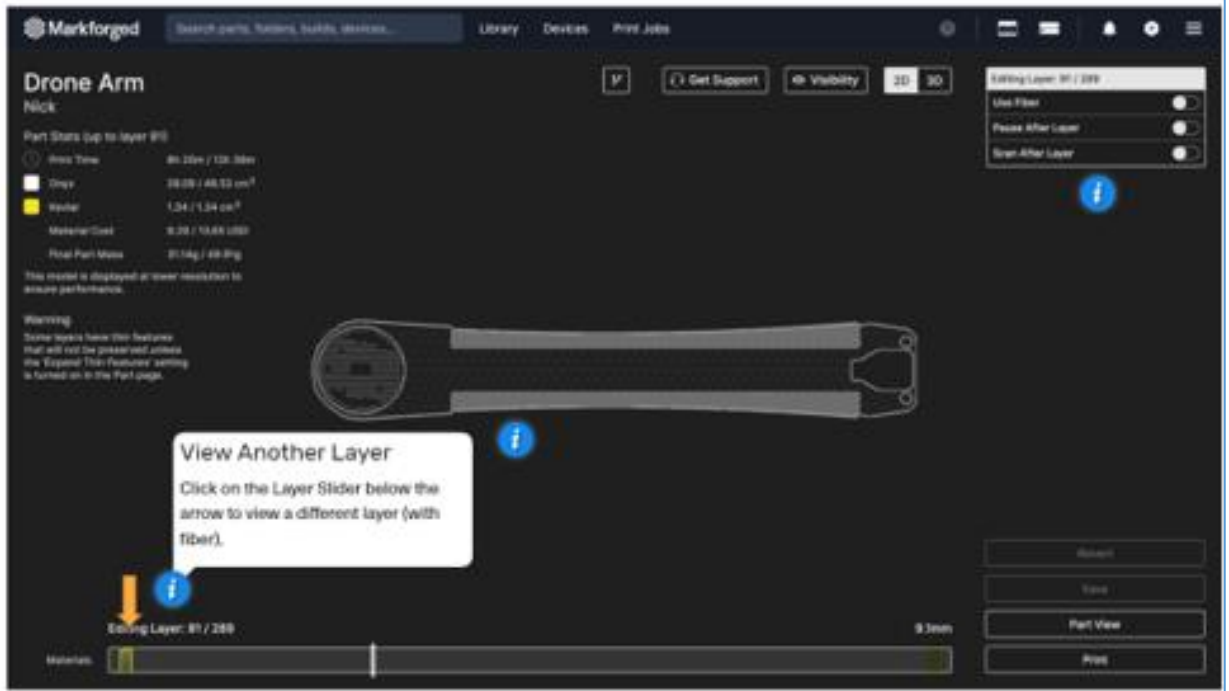
C1.5 - Fundamentals of Eiger

The screenshot shows the Markforged Eiger software interface. The main window displays a 3D model of a 'Drone Arm' part. On the left, there is a 'Part Stats' panel for layer 910, showing a print time of 6h 20m / 12h 39m, a volume of 28.09 / 46.52 cm<sup>3</sup>, a material cost of 9.29 / 13.65 USD, and a final part mass of 31.14g / 49.91g. The material is listed as Onyx. A warning message states: 'Some layers have thin features that will not be preserved unless the "Expand Thin Features" setting is turned on in the Part page.' The 'Layer Settings' panel on the right is collapsed, showing 'Use Fiber', 'Pause After Layer', and 'Scan After Layer' all turned off. A callout box titled 'Layer Settings - No Fiber' explains: 'When a layer is not configured with fiber, the layer settings panel collapses and hides fiber-specific settings. Simply toggle Use Fiber on to show the fiber settings.' The interface includes a search bar, navigation buttons (Library, Devices, Print Jobs), and a bottom status bar showing 'Editing Layer: 91 / 289' and a 9.1mm scale.

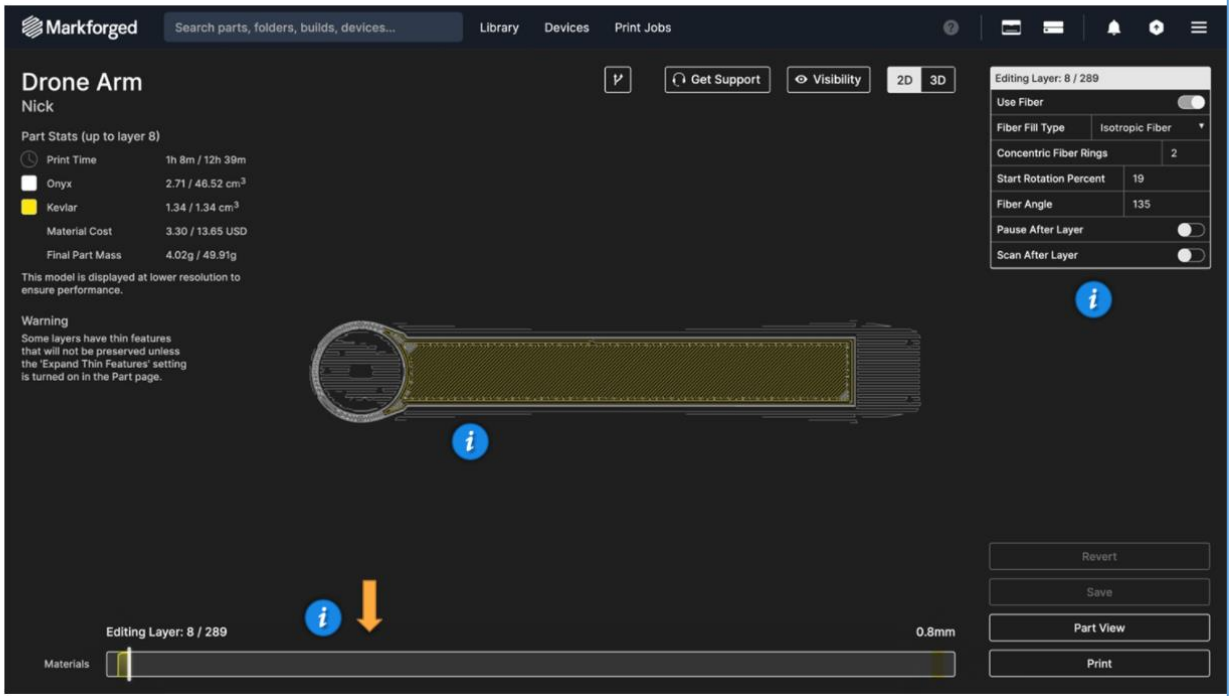
C1.5 - Fundamentals of Eiger

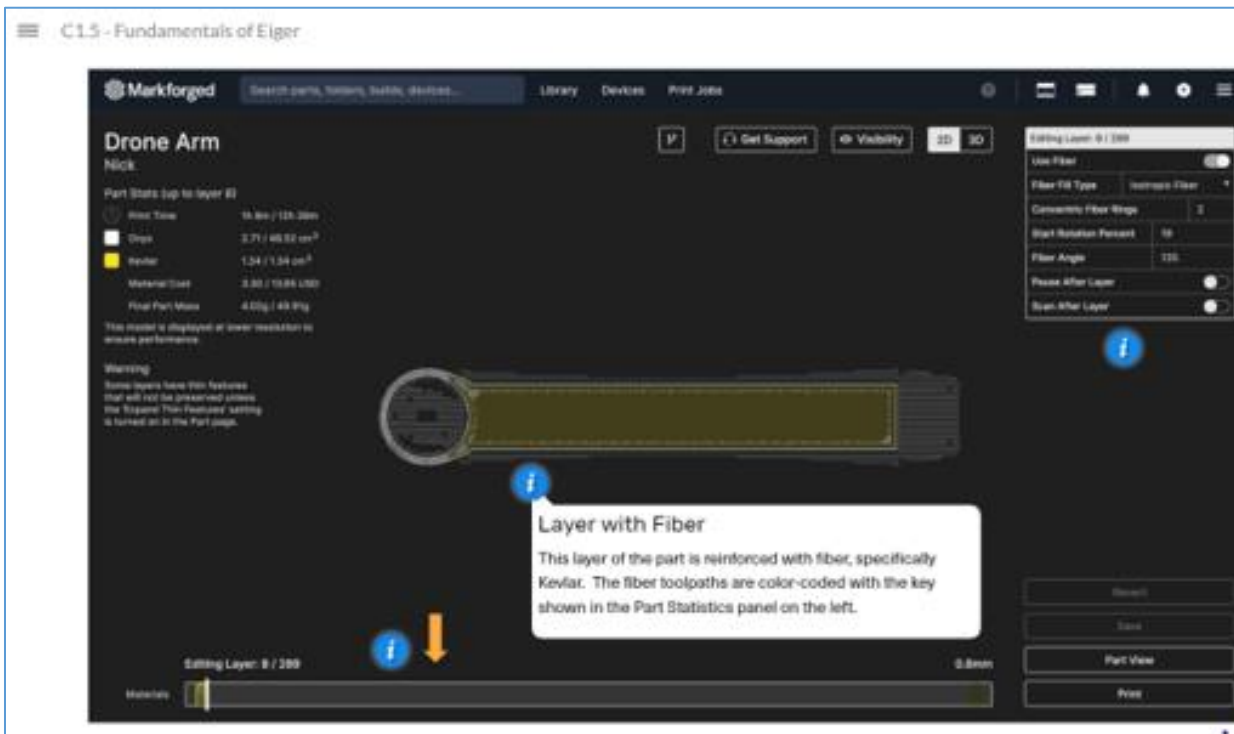
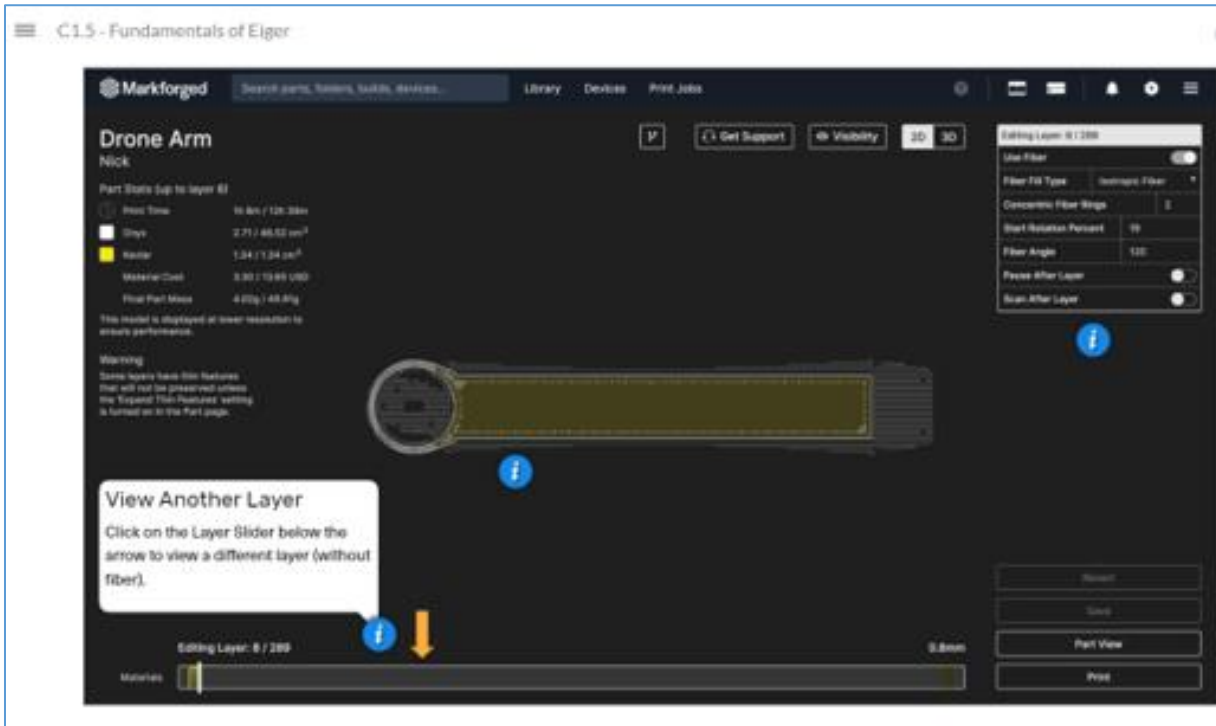
This screenshot shows the same Markforged Eiger interface as the previous one, but with the 'Use Fiber' toggle in the 'Layer Settings' panel turned on. The 'Part Stats' panel now shows a print time of 6h 20m / 12h 39m, a volume of 28.09 / 46.52 cm<sup>3</sup>, a material cost of 9.29 / 13.65 USD, and a final part mass of 31.14g / 49.91g. The material is listed as Kevlar. The warning message remains the same. The 'Layer Settings' panel is now expanded, showing 'Use Fiber' (checked), 'Pause After Layer', and 'Scan After Layer'. The bottom status bar shows 'Editing Layer: 91 / 289' and a 9.1mm scale. The interface also includes a search bar, navigation buttons, and a bottom bar with 'Revert', 'Save', 'Part View', and 'Print' buttons.

C1.5 - Fundamentals of Eiger

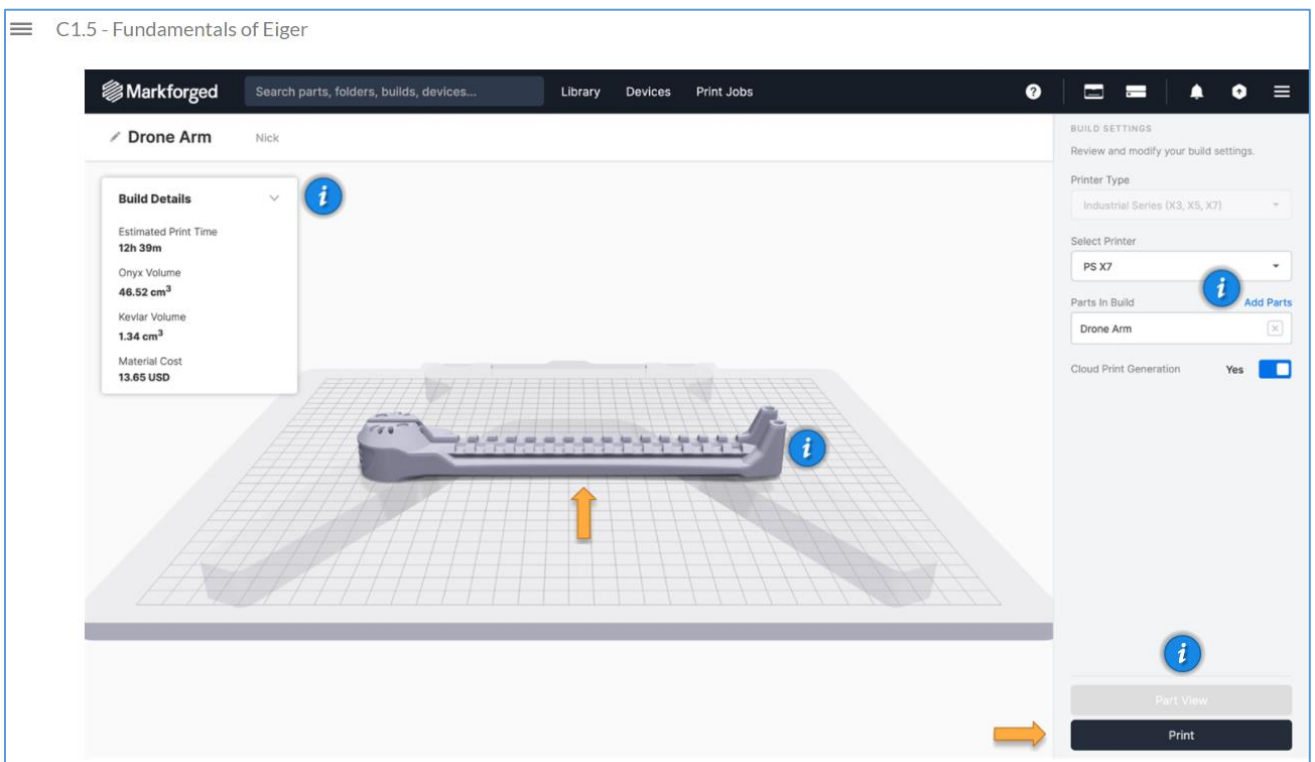
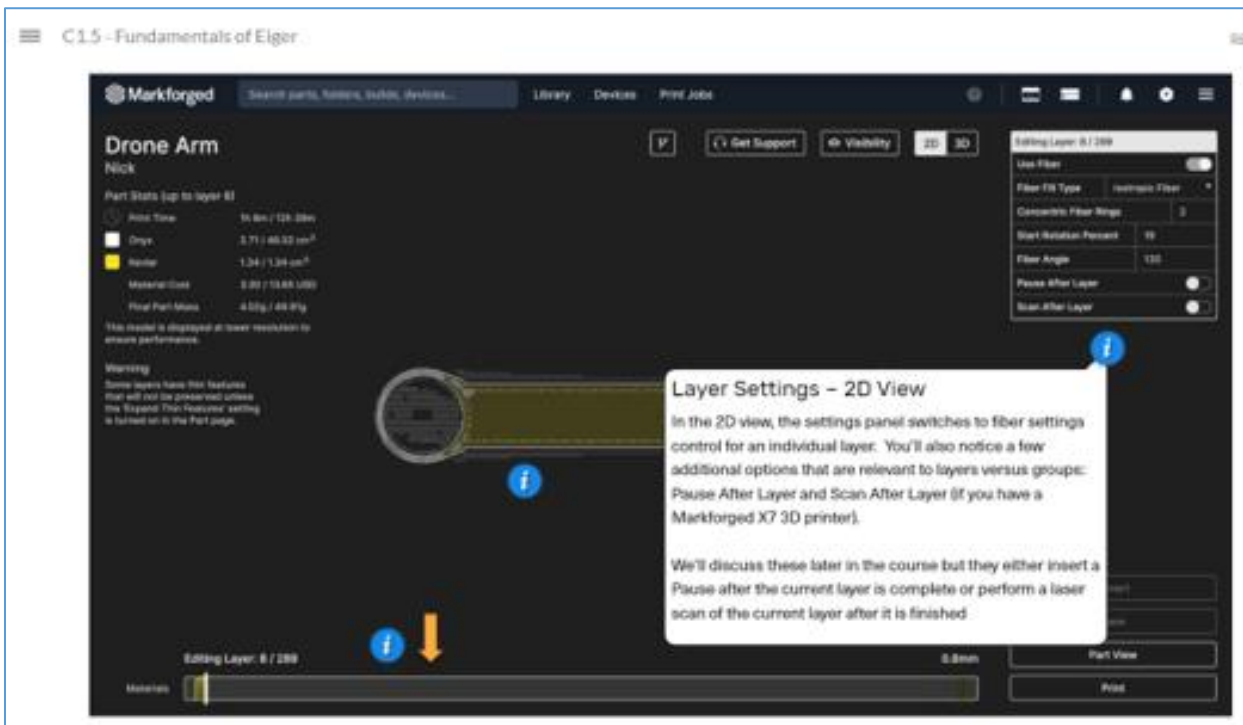


C1.5 - Fundamentals of Eiger



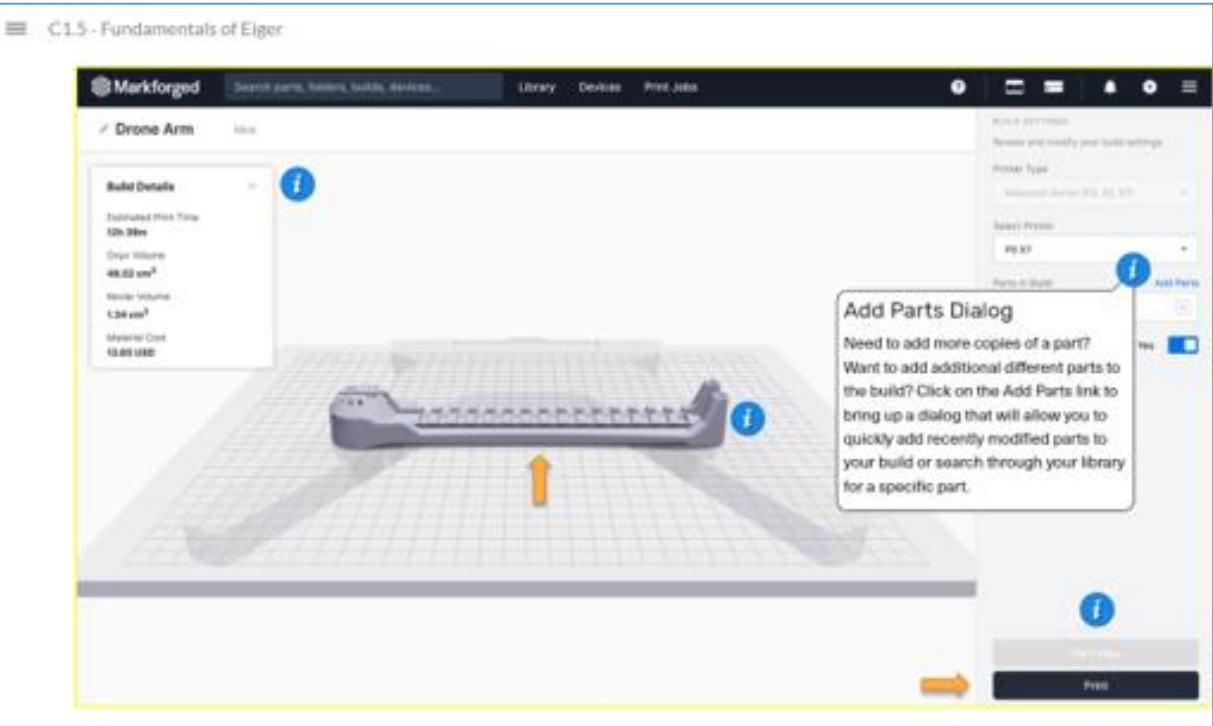
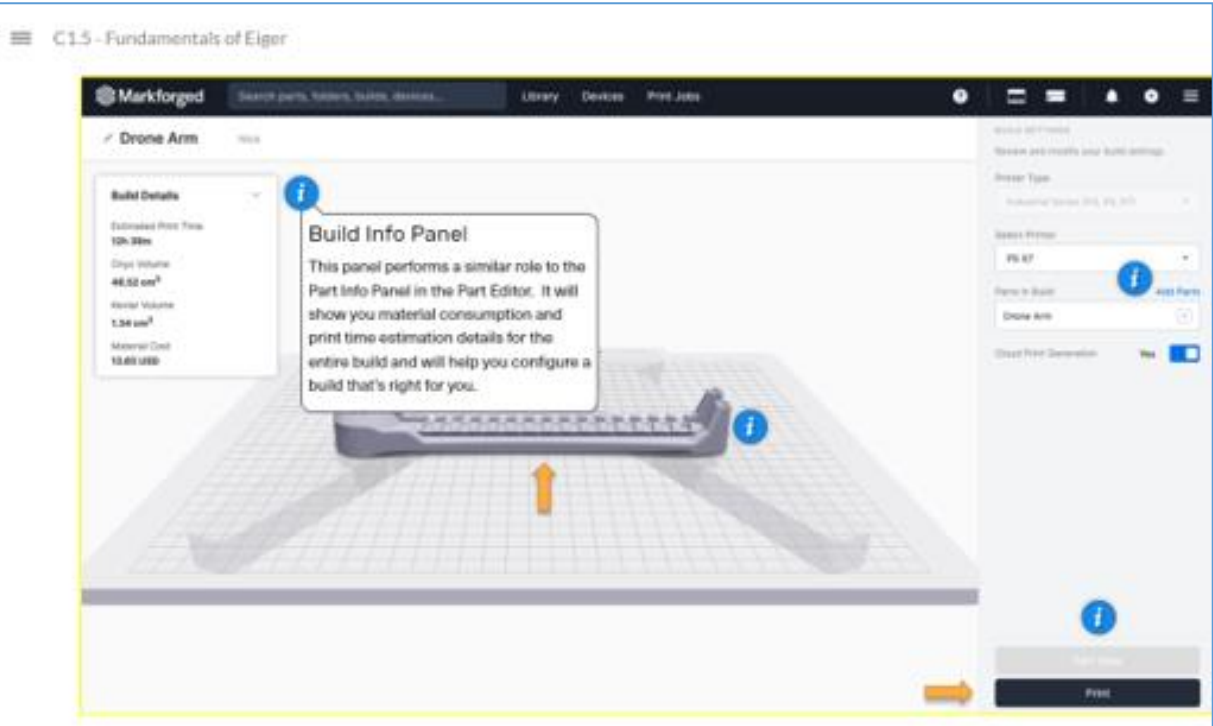


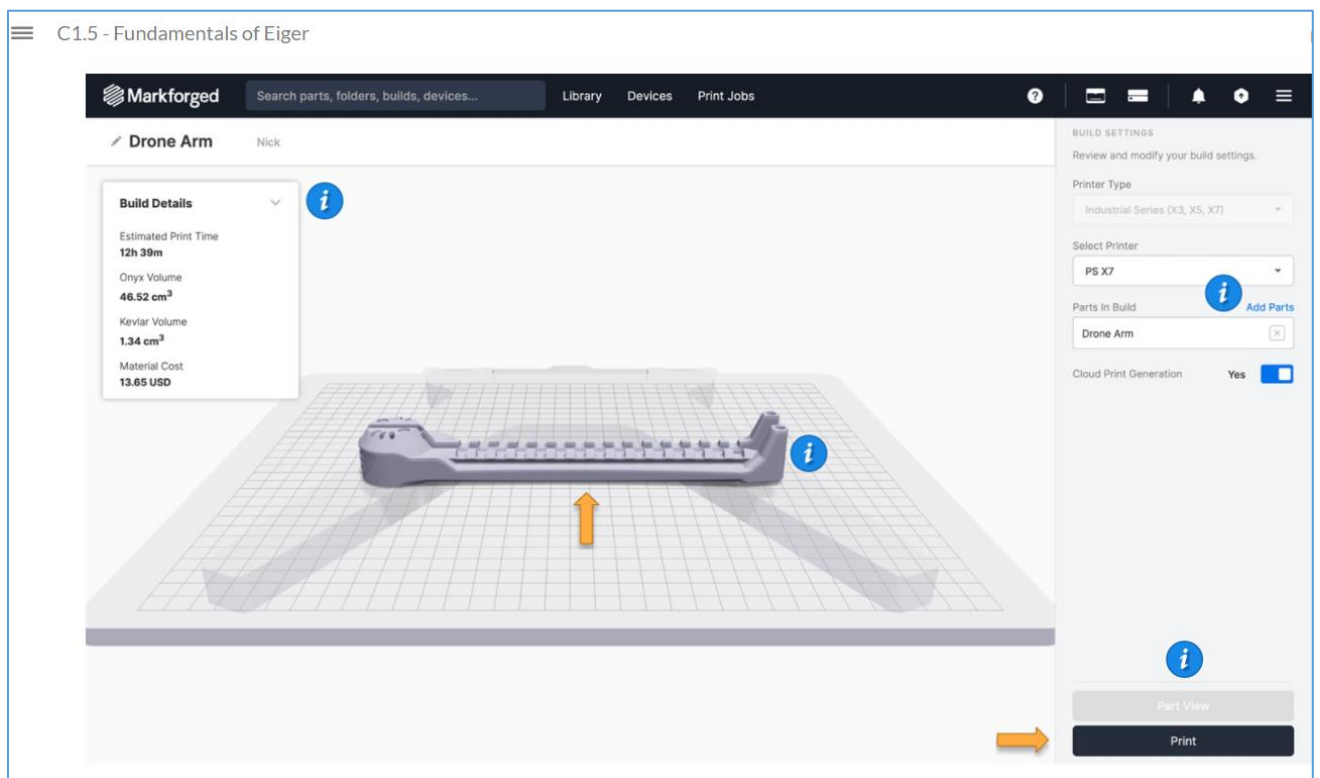
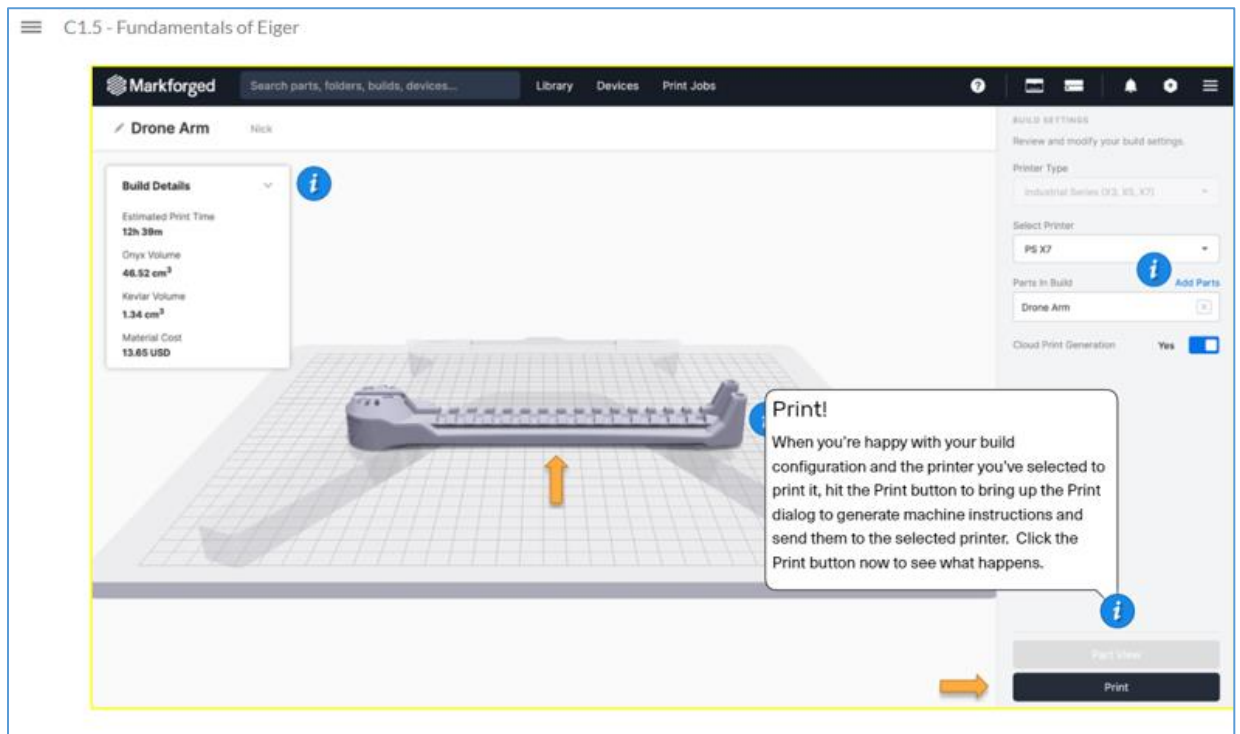




- **Setting up a Print in the Build Editor**







- Pijl bij Part.

**Build Details**

- Estimated Print Time: 12h 39m
- Onyx Volume: 46.52 cm<sup>3</sup>
- Kevlar Volume: 1.34 cm<sup>3</sup>
- Material Cost: 13.65 USD

**De-select a Part**  
 Done re-orienting a part on the print bed? Just click anywhere else on the page to de-select it!

**BUILD SETTINGS**  
 Review and modify your build settings.

Printer Type: Industrial Series (X3, X5, X7)

Select Printer: PS X7

Parts In Build: Drone Arm

Cloud Print Generation: Yes

Current Selection: Drone Arm, Version 2  
 X: 164.94, Y: 144.95

Part View: Drone Arm  
 Print

**Build Details**

- Estimated Print Time: 12h 39m
- Onyx Volume: 46.52 cm<sup>3</sup>
- Kevlar Volume: 1.34 cm<sup>3</sup>
- Material Cost: 13.65 USD

**Selected Part**  
 Notice that the drone arm has turned a darker blue? This indicates that it is the currently selected part.

When you select a part, an orientation settings section appears in the Build Settings sidebar to your right. With those tools you can manually enter precise values to re-orient the part. You can also click and drag the part to quickly re-position it around the print bed.

**BUILD SETTINGS**  
 Review and modify your build settings.

Printer Type: Industrial Series (X3, X5, X7)

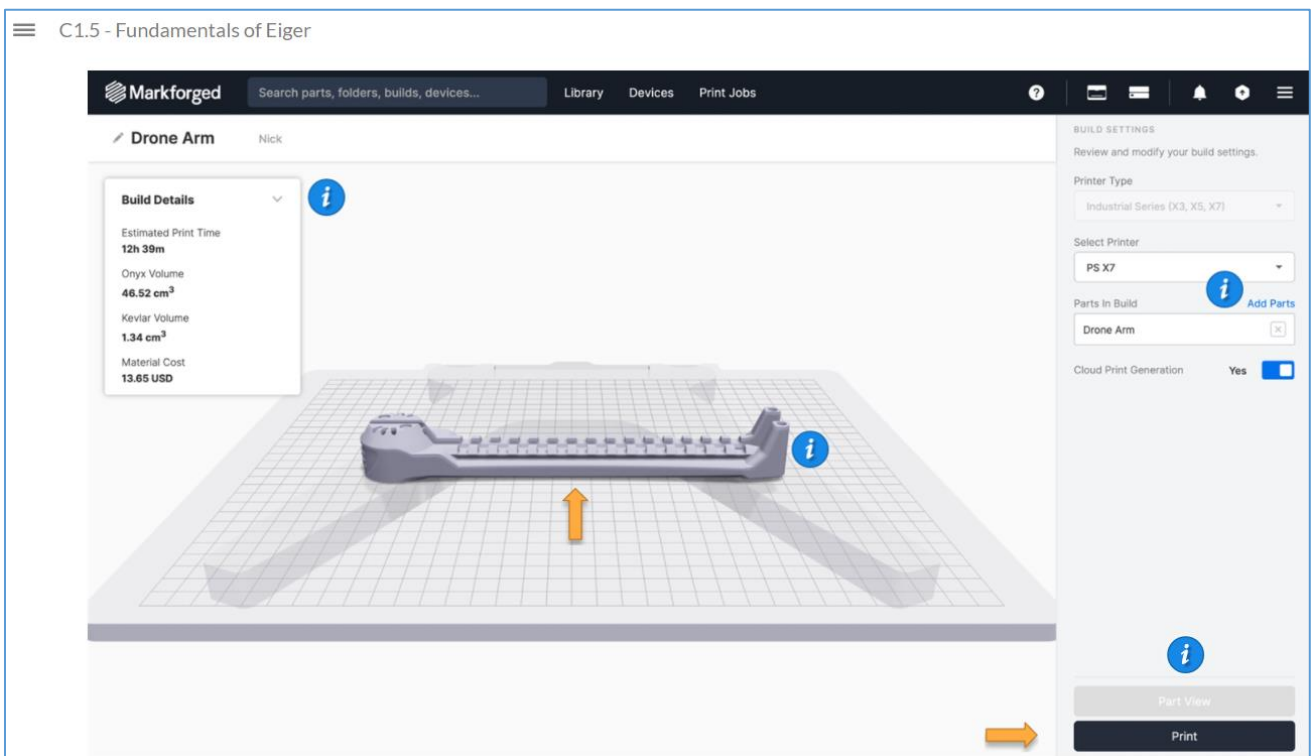
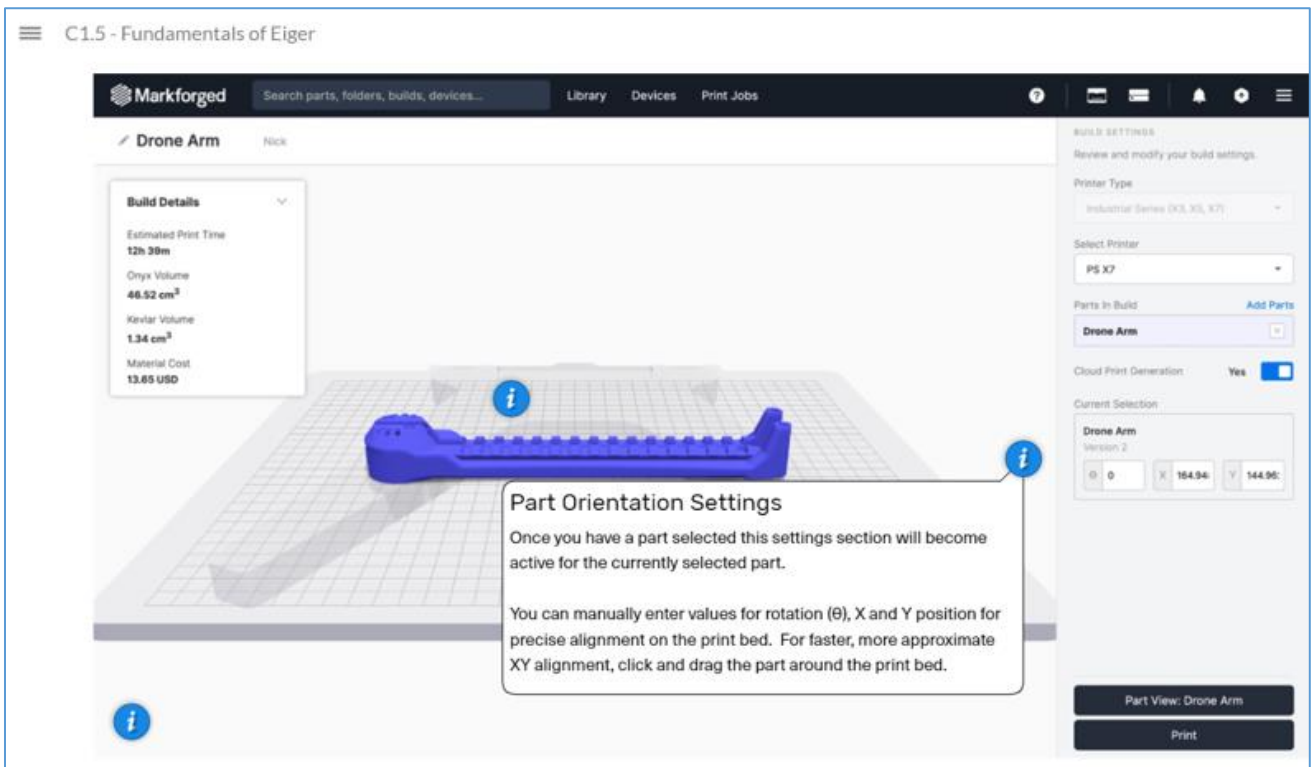
Select Printer: PS X7

Parts In Build: Drone Arm

Cloud Print Generation: Yes

Current Selection: Drone Arm, Version 2  
 X: 164.94, Y: 144.95

Part View: Drone Arm  
 Print



- Pijl bij Print.

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**Print to "PS X7"**

PRINT DETAILS - DRONE ARM

Plastic Volume: 46.52 cm<sup>3</sup>

Fiber Volume: 1.34 cm<sup>3</sup>

Job Duration: 12h 39m

Estimated Queue Time: 3d 20h 30m

STATUS

PS X7 is currently unable to print DRONE ARM, but you can add the print to its queue.

Add to Queue Print Next

Exit the Print Dialog  
Not ready to print just yet? Click anywhere else on the page to exit the dialog!

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WORKSPACE

Library

Parts

My Parts

Folders

Buils

ACTIVITY

Devices

Print Jobs

Wash Jobs

Sinter Jobs

Markforged Professional Services

5 Users

Devices

Filters

Register Device

Device Name	Model	Group	Status	Progress	Time	Type	Queue
Mark Two	House Sparrow	Default Device Group	Print Paused	0%	1h 29m	Printer	No Queue
X7	Mark X Copilot	Default Device Group	Printing	~25%	16h 52m	Printer	No Queue
X7	Mark X Demo Printer	Default Device Group	Printing	~25%	17h 00m	Printer	No Queue
Metal X	Metal XD	Default Device Group	Out of Material	0%		Printer	No Queue
Metal X	Mjölñir	Default Device Group	Print Paused	0%	1d 07h 48m	Printer	No Queue
Mark Two	Mr. Wahlberg	Default Device Group	Printing	~50%	34m	Printer	No Queue
Metal X	Nebuchadnezzar	Default Device Group	Printing	~25%	1d 07h 23m	Printer	No Queue
Mark Two	Nefertiti	Default Device Group	Print Bed Needs Clearing	0%		Printer	No Queue
Mark Two	Old Guy	NPM Swab Campaign	Printing	~50%	1h 36m	Printer	No Queue
Mark Two	Radagast The Brown	Default Device Group	Printing	~50%	4h 52m	Printer	No Queue

- Fleet Status, the Devices Page and Detailed Device Info

Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

WORKSPACE  
Library  
Parts  
My Parts  
Folders  
Builds

ACTIVITY  
Devices  
Print Jobs  
Wash Jobs  
Sinter Jobs

Markforged Professional Services  
5 Users

Devices > Kwolek X7

Device Up To Date Download Logs

Ready

Preheat Plastic  
Preheat Fiber  
Cool Printer  
Stop

STATUS

Plastic Temperature 24°C Loaded Plastic Material ● Onyx FR 477 cm<sup>3</sup> left

Fiber Temperature 25°C Loaded Fiber Material ● Carbon Fiber --

PRINT QUEUE

The print queue for Kwolek is empty  
To queue a print, select this printer from the Select Printer dropdown on the Build Details page.

Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

WORKSPACE  
Library  
Parts  
My Parts  
Folders  
Builds

ACTIVITY  
Devices  
Print Jobs  
Wash Jobs  
Sinter Jobs

Markforged Professional Services  
5 Users

Devices > Kwolek X7

Device Up To Date Download Logs

Fiber Temperature 24°C Loaded Fiber Material ● Onyx FR 477 cm<sup>3</sup> left

Fiber Temperature 25°C Loaded Fiber Material ● Carbon Fiber --

PRINT QUEUE

The print queue for Kwolek is empty  
To queue a print, select this printer from the Select Printer dropdown on the Build Details page.

PRINT HISTORY

Filter by print job name... Owner (any) Material (any) Status (any) Has Images Has Scans

Print	Materials	User	Date	Print Time	Rating
pipette-clip-v1	● Onyx	Nick	May 21, 2020	10h 33m	Rate Print
pipette-clip-v1	● Onyx	Nick	May 21, 2020	28m	Rate Print
pipette-clip-unit-test	● Onyx	Nick	May 21, 2020	11h 38m	Rate Print
vacuum-unit-test	● Onyx	Nick	May 18, 2020	3h 56m	Rate Print
vacuum-unit-test	● Onyx	Nick	May 17, 2020	13m	Rate Print

- Scrolling down.



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**Markforged** Search parts, folders, builds, devices... Library Devices Print Jobs

Printers > Markforged X7 X7 Update Device Download Logs ...

Print	Materials	User	Date	Print Time	Rating
pipette-clip-v1	Onyx	Nick	May 21, 2020	10h 33m	Rate Print <span>...</span>
pipette-clip-v1	Onyx	Nick	May 21, 2020	28m	<span>...</span>
pipette-clip-unit-test	Onyx	Nick	May 21, 2020	11h 38m	<span>...</span>
vacuum-unit-test	Onyx	Nick	May 18, 2020	3h 56m	<span>...</span>
pipette-clip-unit-test	Onyx	Nick	May 17, 2020	13m	Rate Print <span>...</span>
vacuum-unit-test	Onyx	Nick	May 17, 2020	3h 5m	Rate Print <span>...</span>
TO PRINT Fifth Try Clean Re-do of Round Design	Onyx	Nick	May 12, 2020	11h 17m	Rate Print <span>...</span>
TO PRINT Fifth Try Clean Re-do of Round Design	Onyx	Nick	May 12, 2020	9h 23m	Rate Print <span>...</span>
Rode Mic Mount - mount-thread-side	Onyx	Nick	May 1, 2020	47m	Rate Print <span>...</span>
Rode Mic Mount - mount-bolt-side	Onyx	Nick	May 1, 2020	50m	Rate Print <span>...</span>
base-unit-test-v1	Onyx	Nick	Apr 26, 2020	31m	Rate Print <span>...</span>
Std. Soffit Vent Cover	Onyx	Nick	Apr 25, 2020	1m	Canceled <span>...</span>
Std. Soffit Vent Cover	Onyx	Nick	Apr 21, 2020	20h 30m	Rate Print <span>...</span>
Std. Soffit Vent Cover	Onyx	Nick	Apr 20, 2020	20h 30m	Rate Print <span>...</span>

Context Menu: Open Build, Print Again, Export Build, View Camera Images

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**Markforged** Search parts, folders, builds, devices... Library Devices Print Jobs

Library Sort by Modified Filters Create Folder Import STL ...

Library

- Parts
- My Parts
- Folders
- Builds

ACTIVITY

- Devices
- Print Jobs ←
- Wash Jobs
- Sinter Jobs

Markforged Professional Services  
5 Users

Library items:

- CNC Tube Bending Die (Nick)
- Design for FFF + CFF (Nick)
- Plunge EDM Test (1) (Cat)
- Locked\_Supports\_-\_U-Joi... (Cat)
- Locked\_Supports\_-\_U-Joi... (Cat)
- Metal Training (Nick)
- Really Advanced Stuff (Nick)
- Foundations of AM (Nick)
- Optimizing Composite Su... (Nick)
- Building a Business Case (Nick)
- Intermediate Eiger Operati... (Nick)
- 20388 Integrated 3 - 203... (Cat)
- Outside Multibody (Cat)
- Inside Multibody (Cat)
- Part Studio 1 (9) (Cat)

- Organization Print History and the Print Jobs Page

**Print Jobs**

Filter by print job name... Owner (any) Material (any) Status (any) Series (any) Printers (any)

Has Images  Has Scans

Print	Materials	Device	User	Date	Print Time	Rating
pipette-clip-v1	Onyx	Markforged X7	Nick	May 21, 2020	10h 33m	Rate Print
pipette-clip-v1	Onyx	Markforged X7	Nick	May 21, 2020	28m	Rate Print
pipette-clip-unit-test	Onyx	Markforged X7	Nick	May 21, 2020	11h 38m	Rate Print
vacuum-unit-test	Onyx	Markforged X7	Nick	May 18, 2020	3h 56m	Rate Print
pipette-clip-unit-test	Onyx	Markforged X7	Nick	May 17, 2020	13m	Rate Print
vacuum-unit-test	Onyx	Markforged X7	Nick	May 17, 2020	3h 5m	Rate Print
TO PRINT Fifth Try Clean Re-do of ...	Onyx	Markforged X7	Nick	May 12, 2020	11h 17m	Rate Print
TO PRINT Fifth Try Clean Re-do of ...	Onyx	Markforged X7	Nick	May 12, 2020	9h 23m	Rate Print
Rode Mic Mount - mount-thread-si...	Onyx	Markforged X7	Nick	May 1, 2020	47m	Rate Print
Rode Mic Mount - mount-bolt-side	Onyx	Harpoon	Nick	May 1, 2020	52m	Rate Print
Rode Mic Mount - mount-thread-side	Onyx	Harpoon	Nick	May 1, 2020	47m	Rate Print

Markforged Professional Services  
5 Users

**Library**

Sort by Modified Filters

Create Folder Import STL

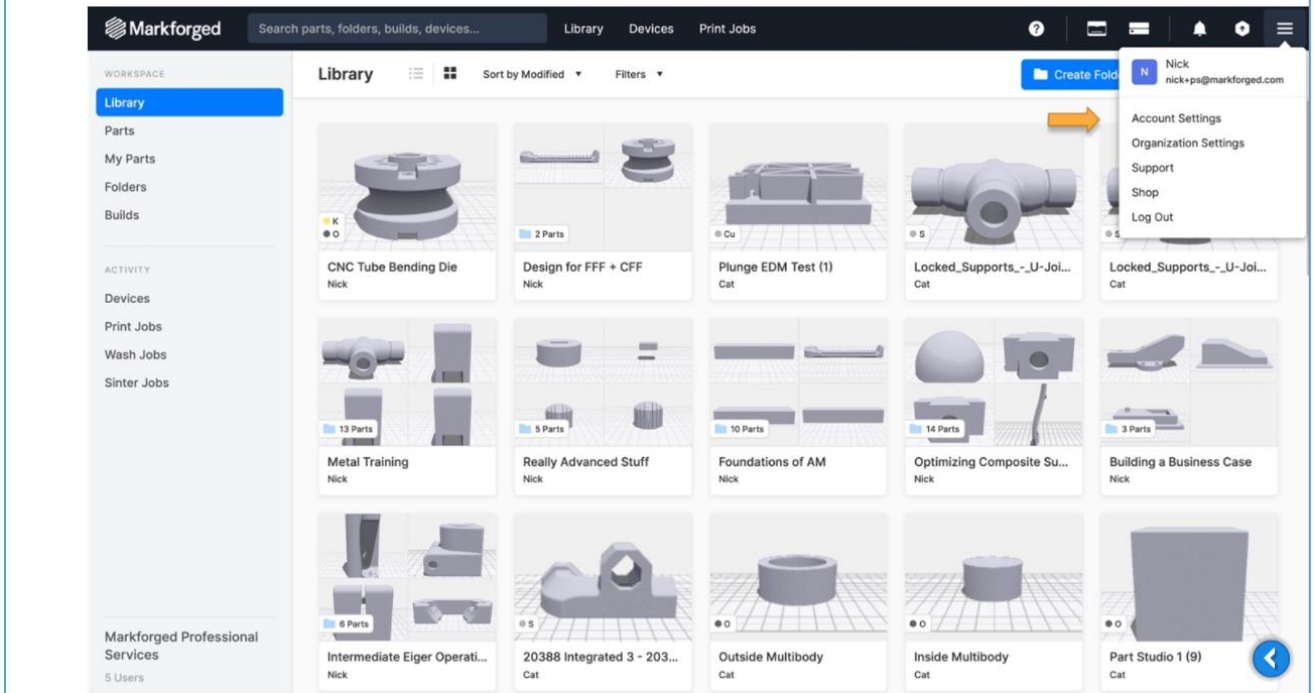
<b>CNC Tube Bending Die</b> Nick	<b>Design for FFF + CFF</b> Nick	<b>Plunge EDM Test (1)</b> Cat	<b>Locked_Supports_-_U-Joi...</b> Cat	<b>Locked_Supports_-_U-Joi...</b> Cat
<b>Metal Training</b> Nick	<b>Really Advanced Stuff</b> Nick	<b>Foundations of AM</b> Nick	<b>Optimizing Composite Su...</b> Nick	<b>Building a Business Case</b> Nick
<b>Intermediate Eiger Operati...</b> Nick	<b>20388 Integrated 3 - 203...</b> Cat	<b>Outside Multibody</b> Cat	<b>Inside Multibody</b> Cat	<b>Part Studio 1 (9)</b> Cat

Markforged Professional Services  
5 Users

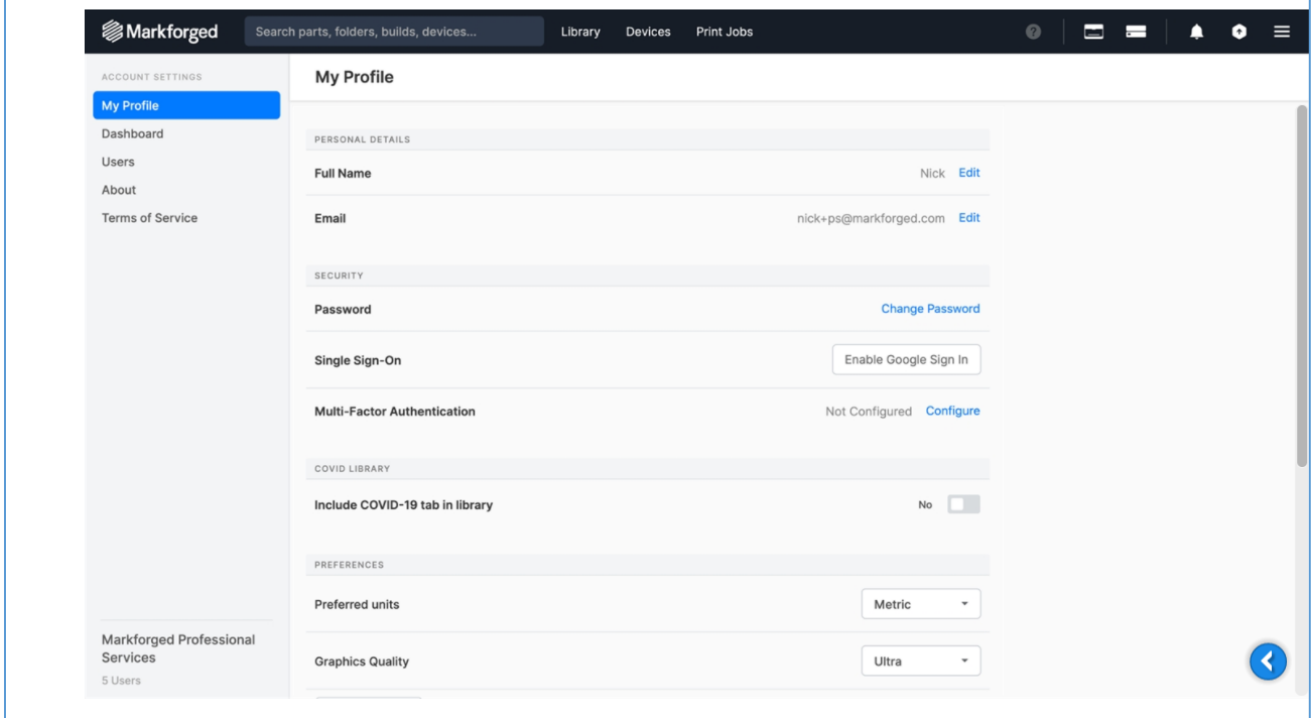
- Personalizing Eiger with Account Settings



C1.5 - Fundamentals of Eiger



C1.5 - Fundamentals of Eiger



Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

ACCOUNT SETTINGS

- My Profile
- Dashboard
- Users
- About
- Terms of Service

Markforged Professional Services  
5 Users

### My Profile

SECURITY

Password [Change Password](#)

Single Sign-On [Enable Google Sign In](#)

Multi-Factor Authentication Not Configured [Configure](#)

COVID LIBRARY

Include COVID-19 tab in library No

PREFERENCES

Preferred units Metric

Graphics Quality Ultra

Enable experimental features On

Activity notification emails On

Hide part settings help tooltips Off

- Organization Insights with the Dashboard

Markforged Search parts, folders, builds, devices... Library Devices Print Jobs

ACCOUNT SETTINGS

- My Profile
- Dashboard
- Users
- About
- Terms of Service

Markforged Professional Services  
5 Users

### Dashboard

15 Devices 42 Users 9378 Parts

#### Print Jobs per Week

Print Jobs

Interval: Week User: All Users

#### Printer Bandwidth by User

Time Span: Past Month Printer: All Printers

#### Material Usage per Week

Primary (cc) Secondary (cc)

#### Parts Uploaded per Week

Parts Uploaded

☰ C1.5 - Fundamentals of Eiger

**Markforged** Search parts, folders, builds, devices... Library Devices Print Jobs

ACCOUNT SETTINGS

- My Profile
- Dashboard**
- Users
- About
- Terms of Service

**Dashboard**

Interval:  Time Span:   
 User:  Printer:

**Material Usage per Week**

Interval:  User:   
 Primary:

**Parts Uploaded per Week**

Interval:  User:

Markforged Professional Services  
5 Users

- Scrolling down...

☰ C1.5 - Fundamentals of Eiger

**Markforged** Search parts, folders, builds, devices... Library Devices Print Jobs

ACCOUNT SETTINGS

- My Profile
- Dashboard**
- Users
- About
- Terms of Service

**Dashboard**

Interval:  User:   
 Primary:  Secondary:

**Print Job History CSV Download**

Printer:  User:   
 Primary:  Secondary:

**Custom Analytics Download**

Time Span:

Markforged Professional Services  
5 Users

- Scrolling further down....



## Eiger Activity: STL-to-Print Workflow

- **Activity: Basic Eiger Workflow**

## Eiger Configure & Slice Workflow



Import



Orient &  
Configure



Slice &  
Upload



Arrange Build &  
Print

- **Eiger Configures & Slice Workflow**

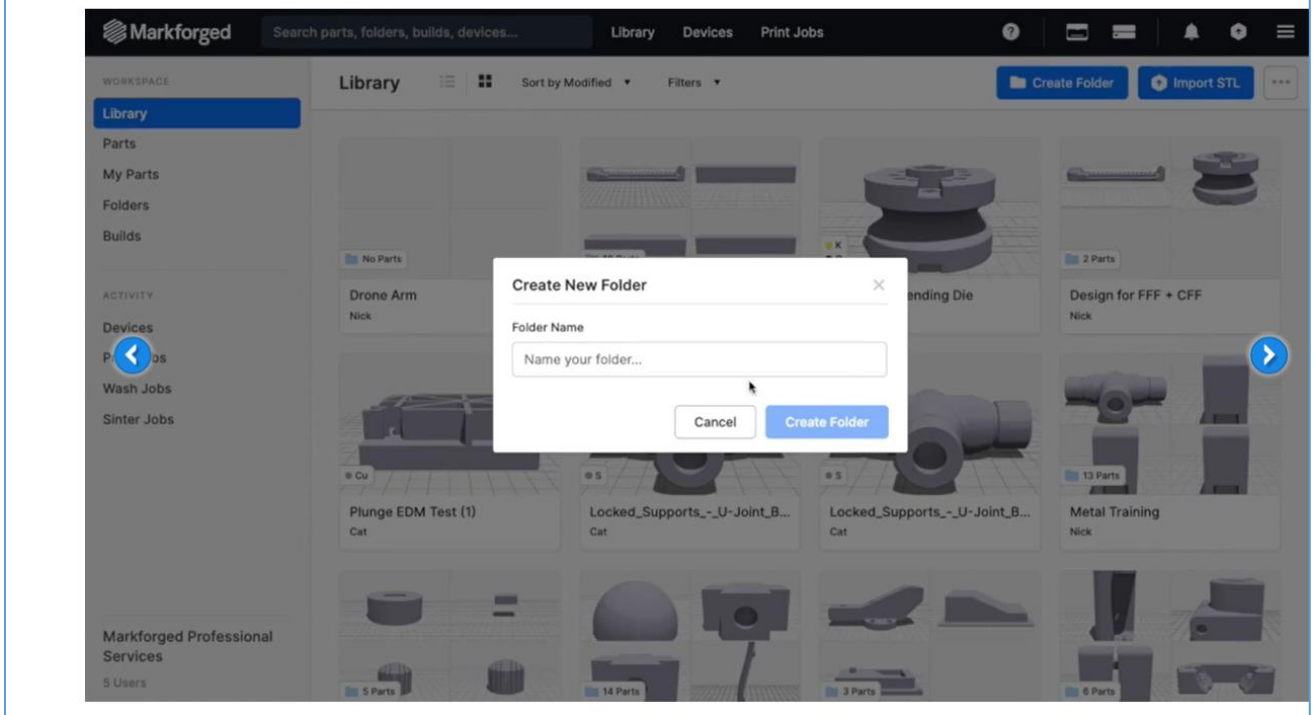
# Basic Eiger Workflow



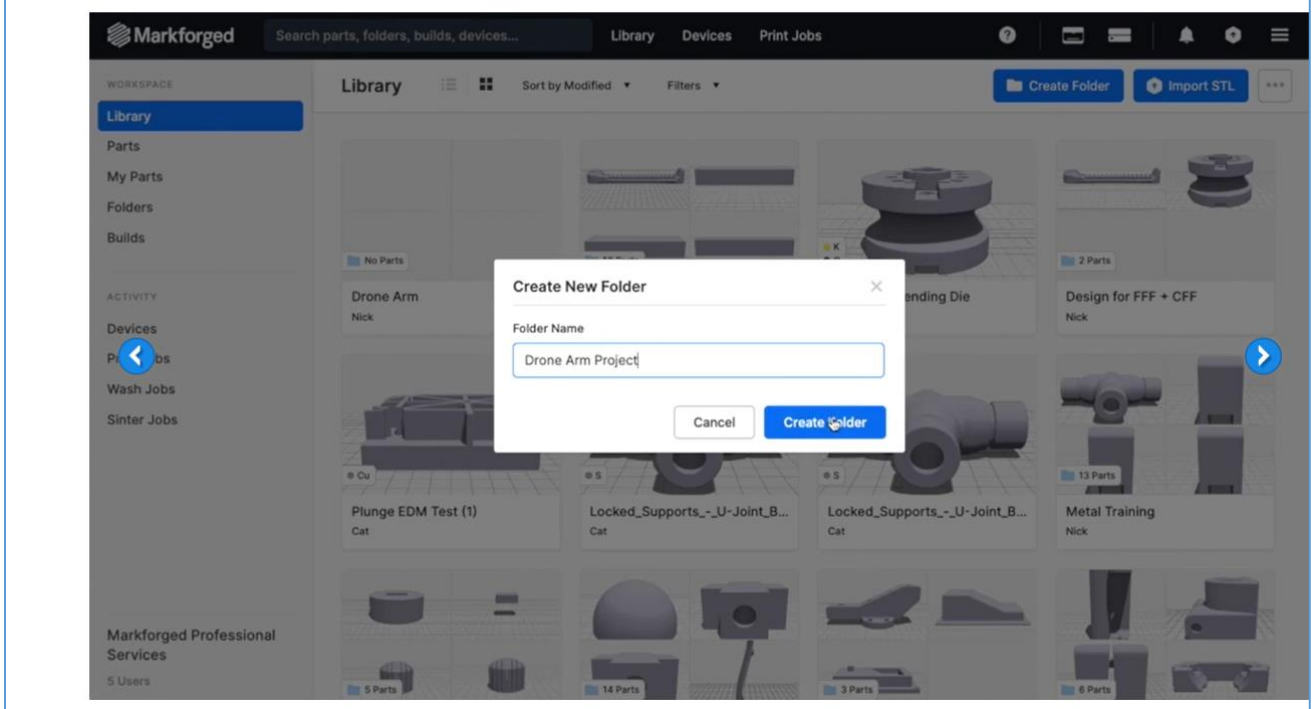
- **STL-to-Part Tutorial**

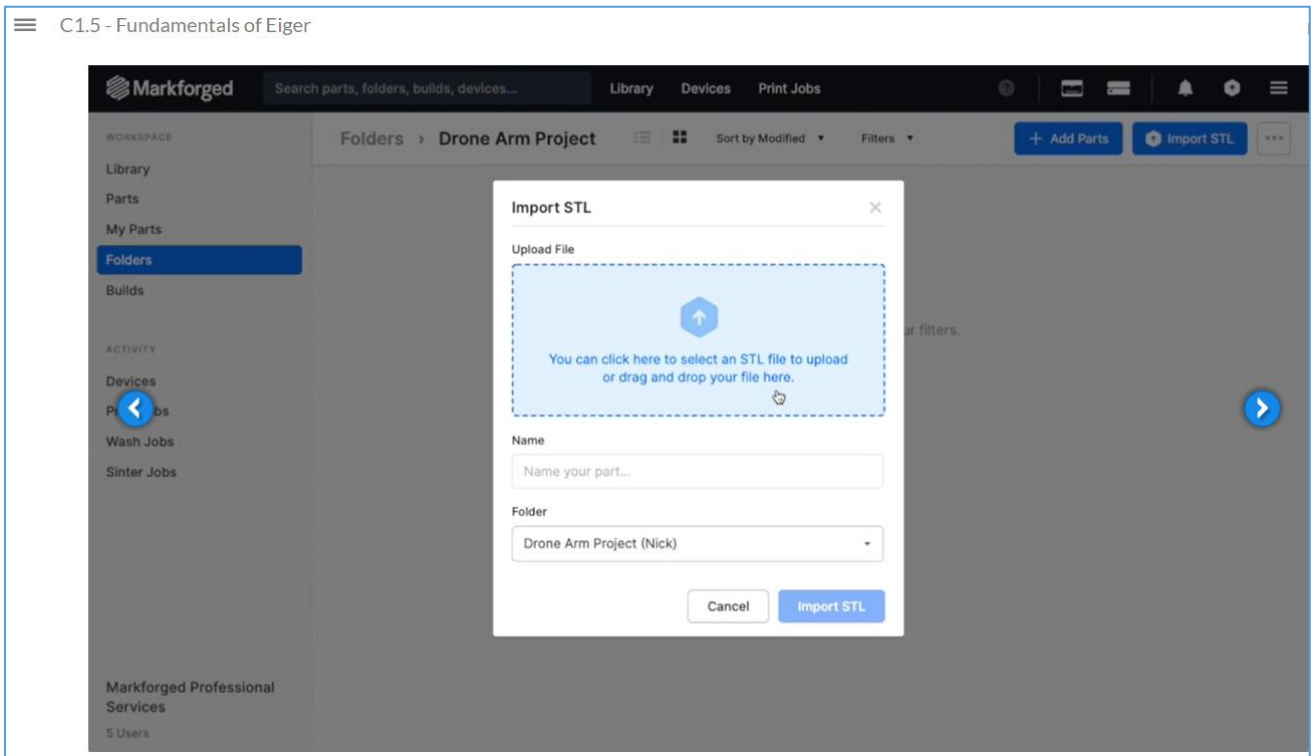
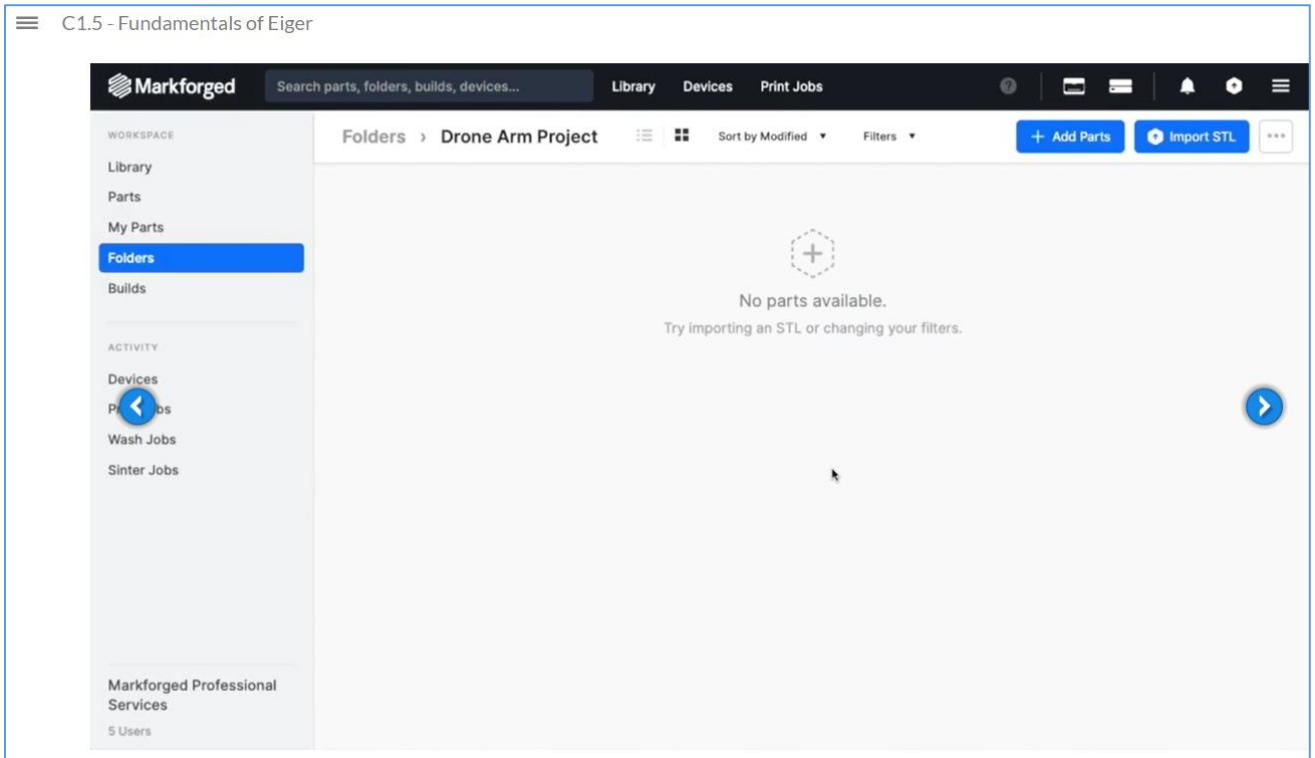
The screenshot displays the Markforged software interface. At the top, there is a search bar and navigation tabs for 'Library', 'Devices', and 'Print Jobs'. A left sidebar contains a 'WORKSPACE' menu with options like 'Library', 'Parts', 'My Parts', 'Folders', and 'Builds', as well as an 'ACTIVITY' section with 'Devices', 'Print Jobs', 'Wash Jobs', and 'Sinter Jobs'. The main area is titled 'Library' and shows a grid of 3D model thumbnails. Each thumbnail includes a part count (e.g., 'No Parts', '10 Parts', '2 Parts', '13 Parts', '5 Parts', '14 Parts', '3 Parts', '6 Parts') and a title such as 'Drone Arm', 'Foundations of AM', 'CNC Tube Bending Die', 'Design for FFF + CFF', 'Plunge EDM Test (1)', 'Locked\_Supports\_-\_U-Joint\_B...', and 'Metal Training'. A blue arrow icon is visible on the right side of the grid.

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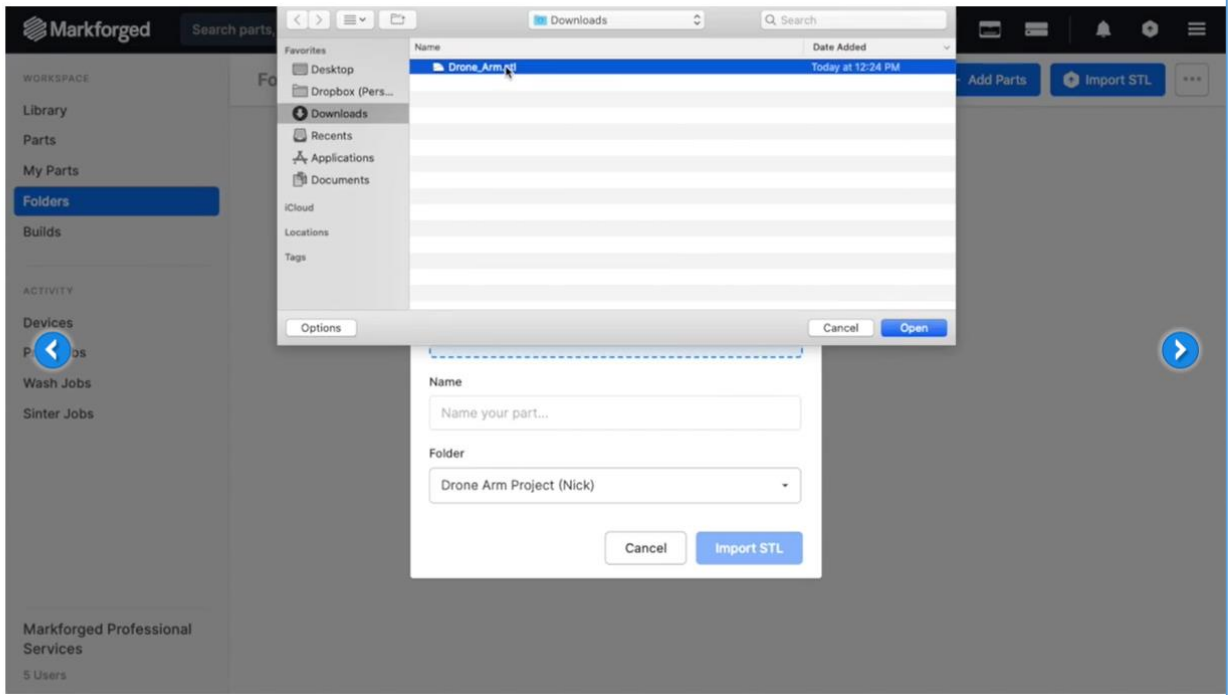
☰ C1.5 - Fundamentals of Eiger



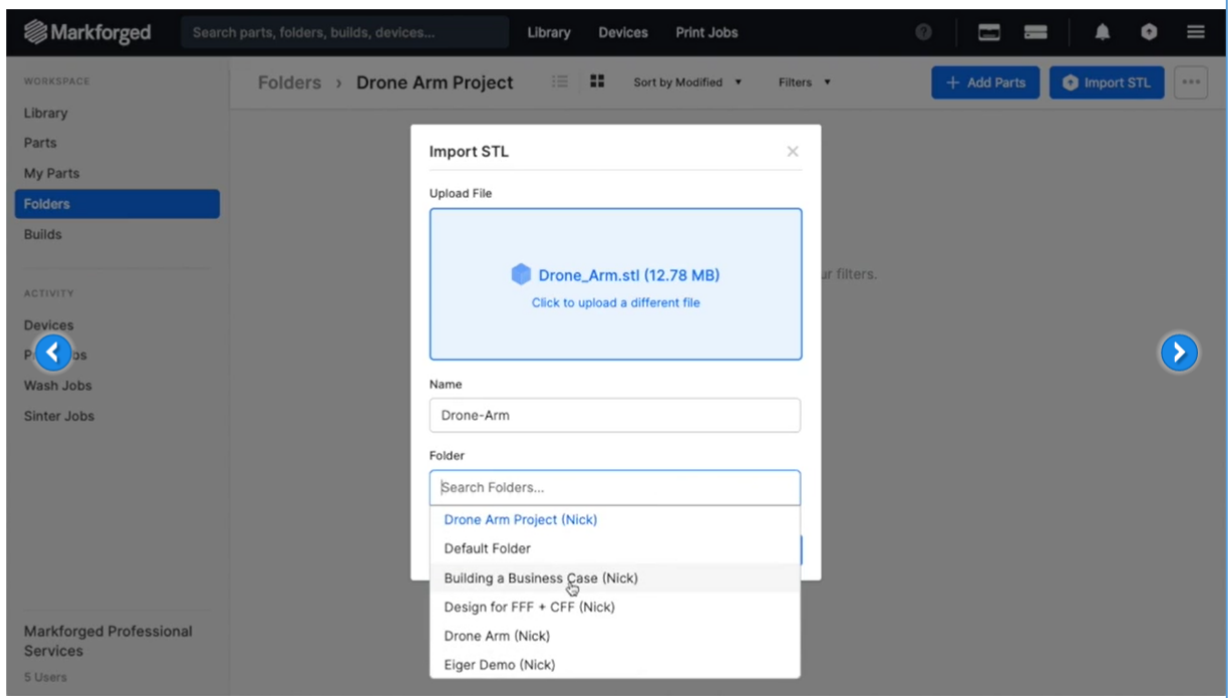




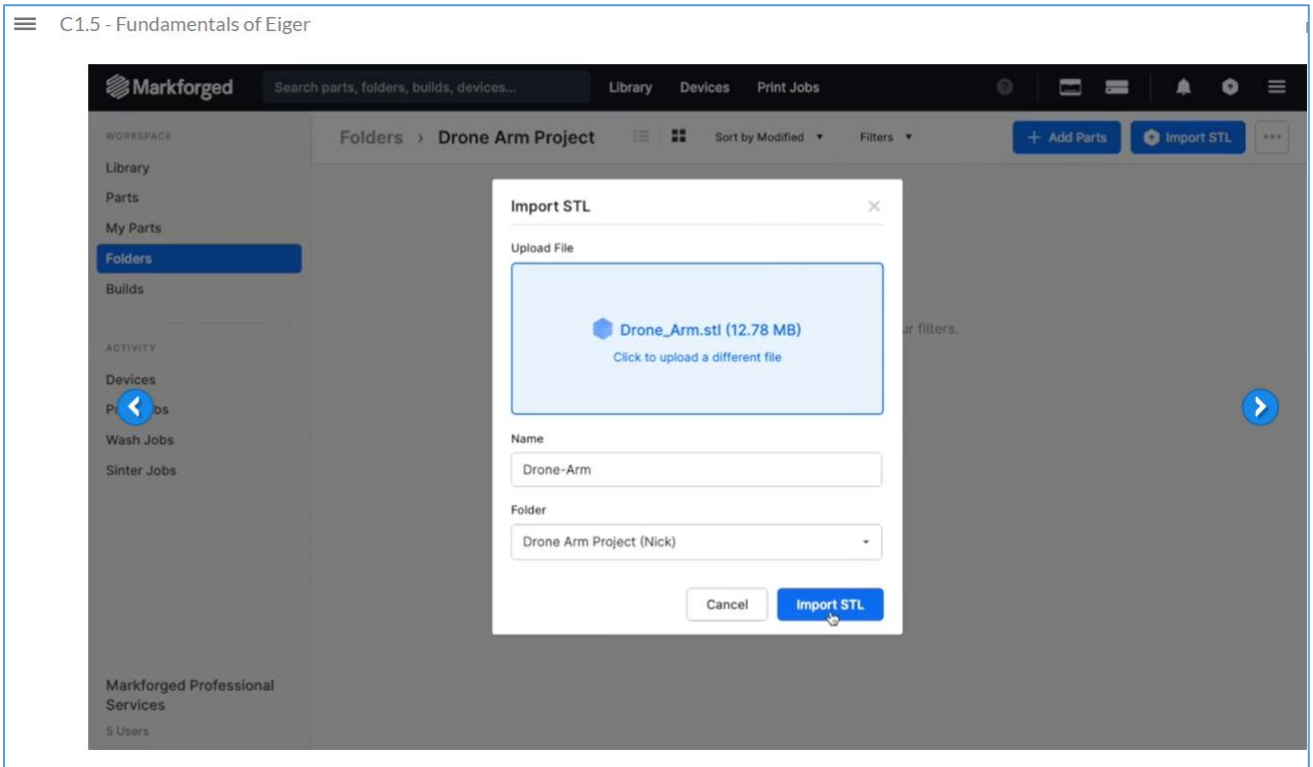
C1.5 - Fundamentals of Eiger



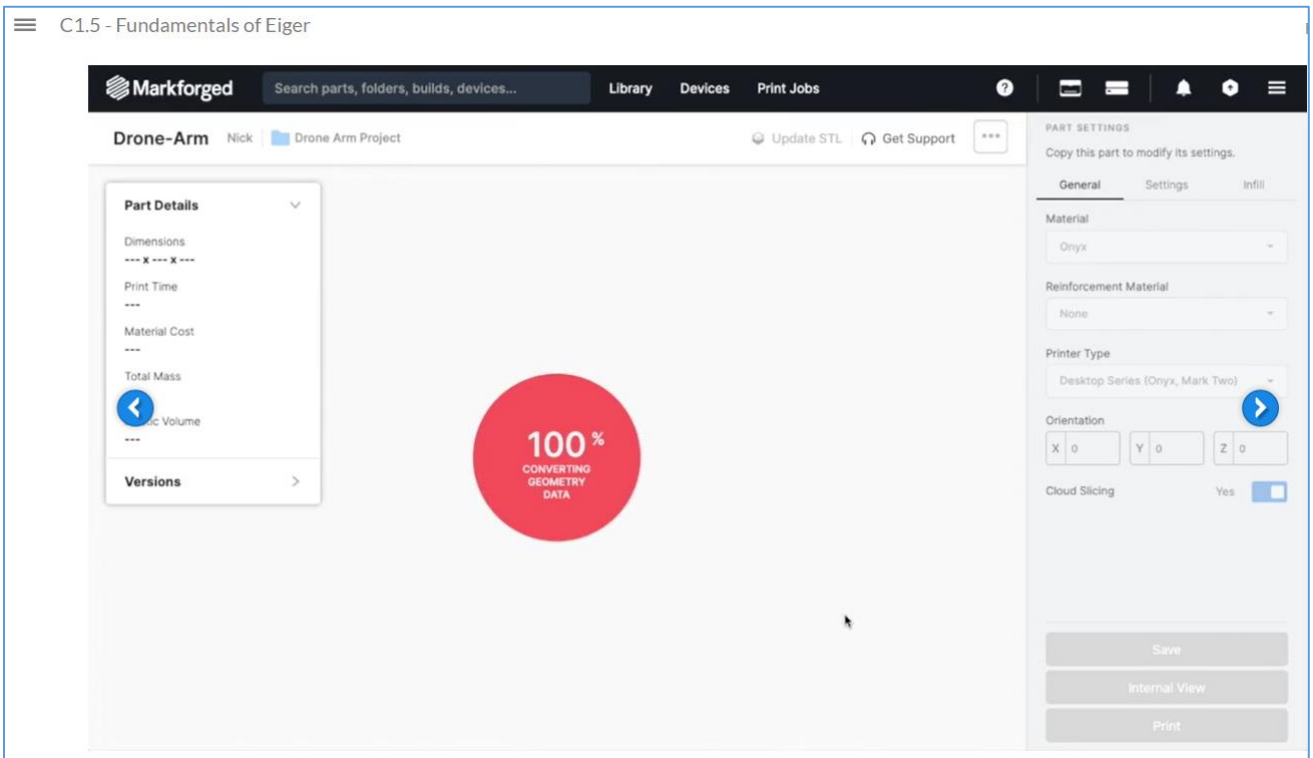
C1.5 - Fundamentals of Eiger

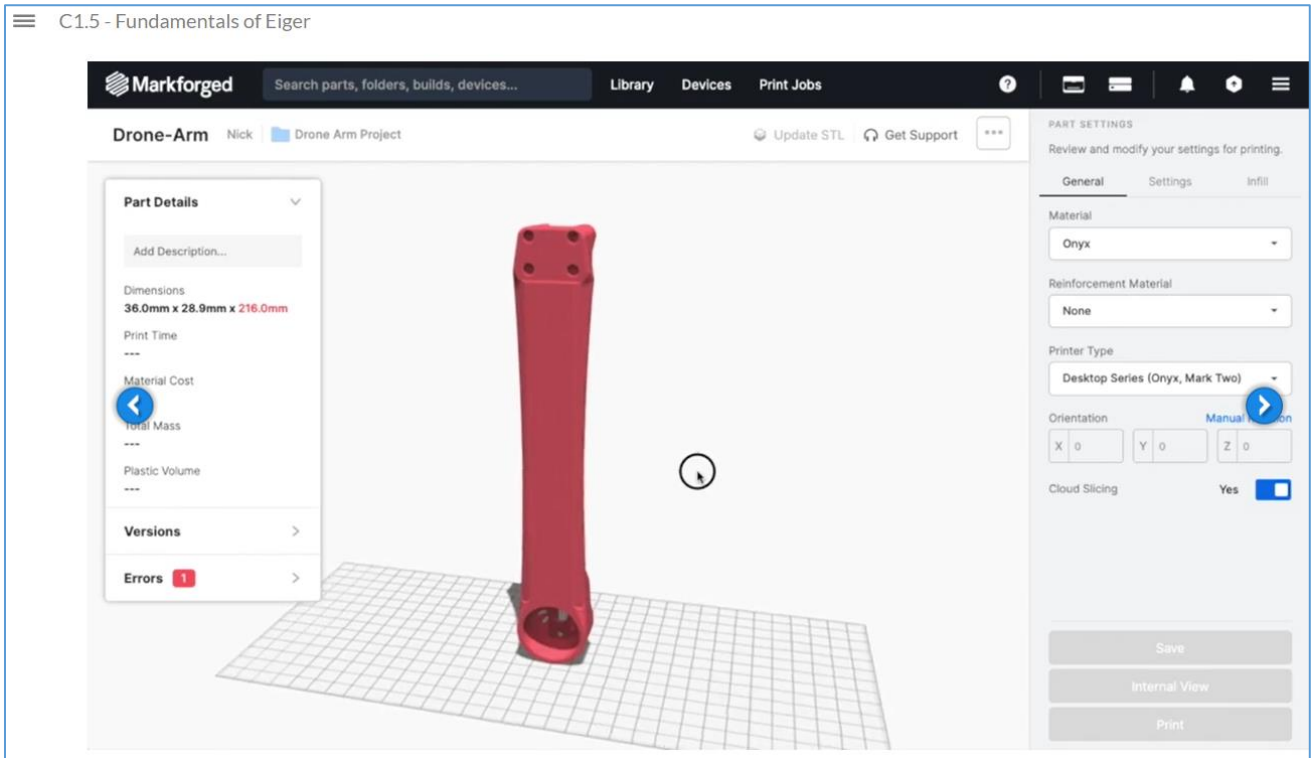


C1.5 - Fundamentals of Eiger

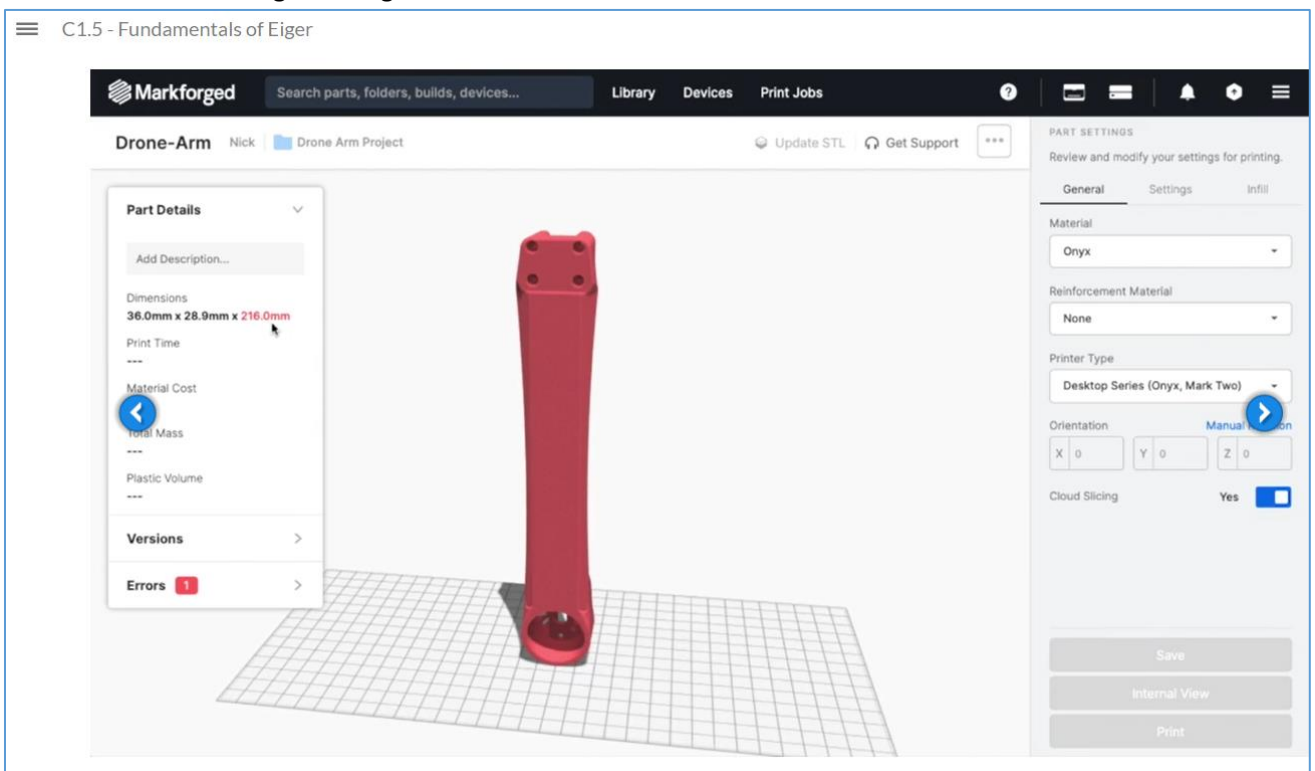


C1.5 - Fundamentals of Eiger

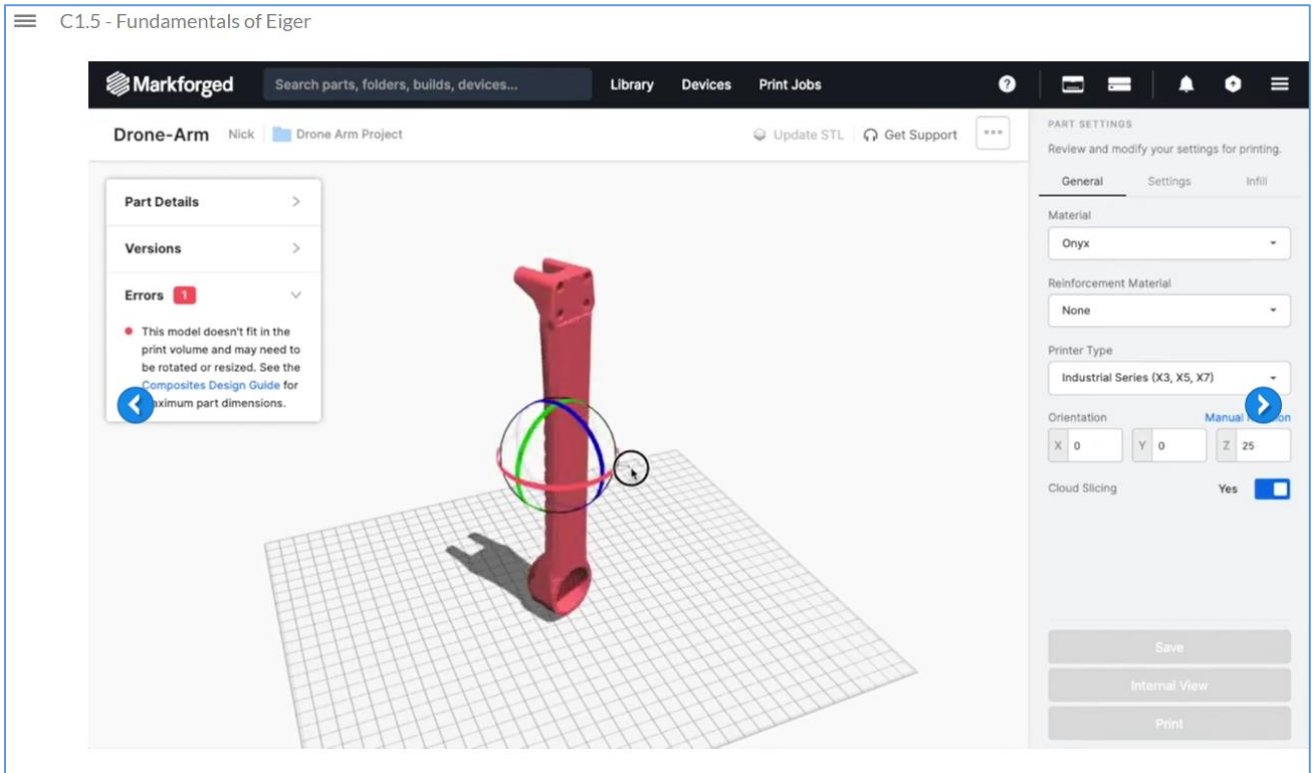




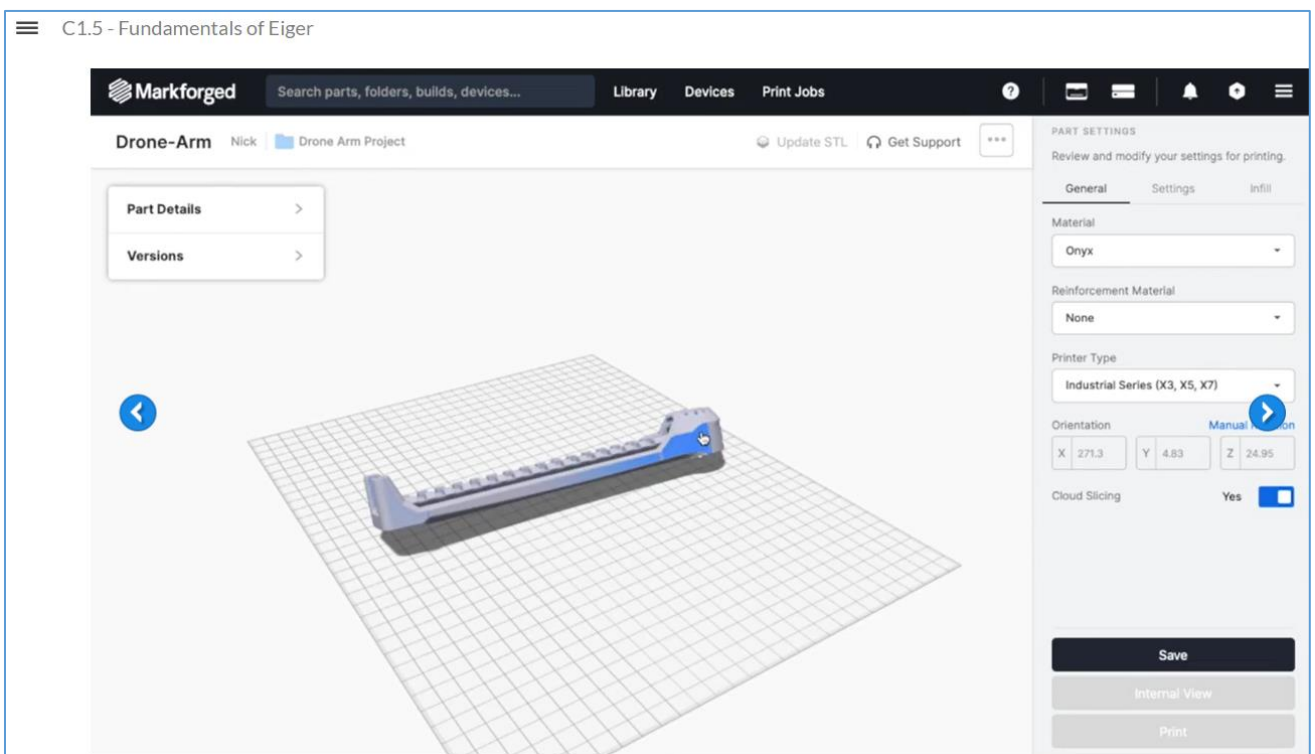
- Red: Something is wrong.



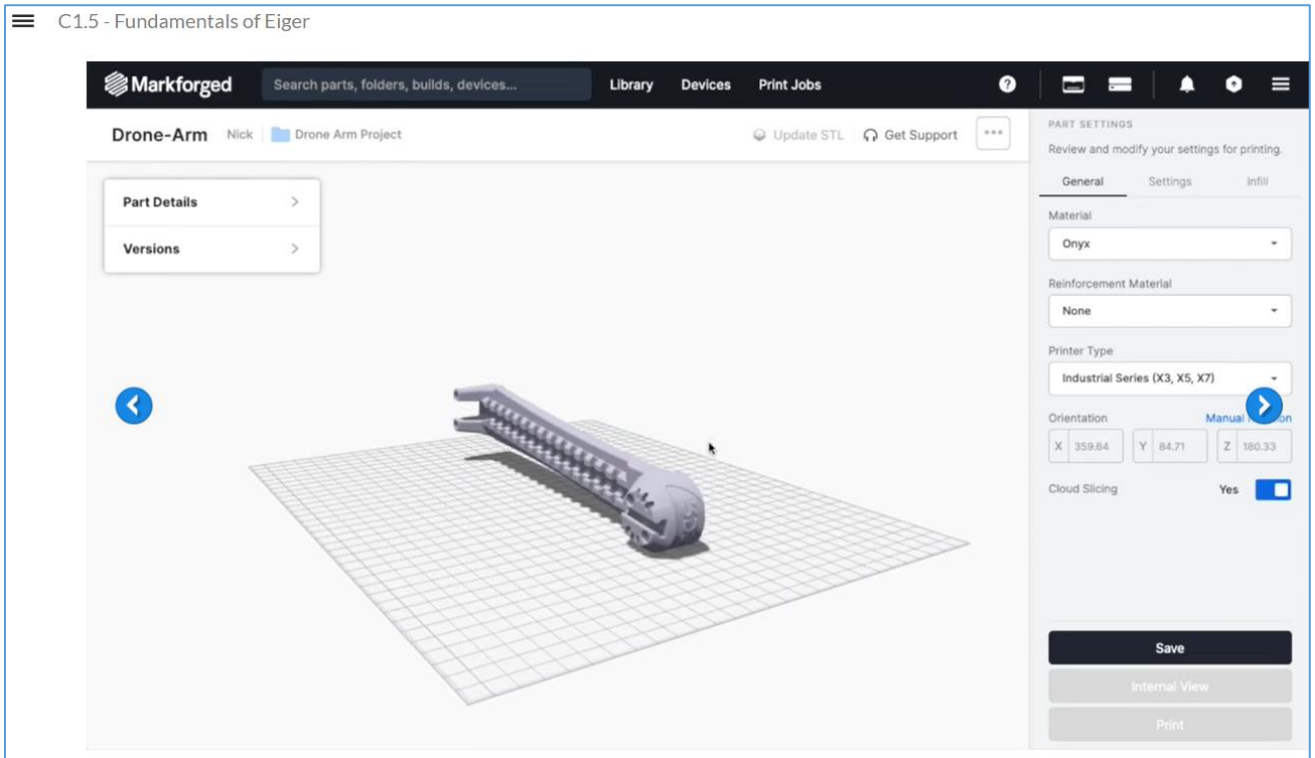
- Exceeds the size in Z-axis.



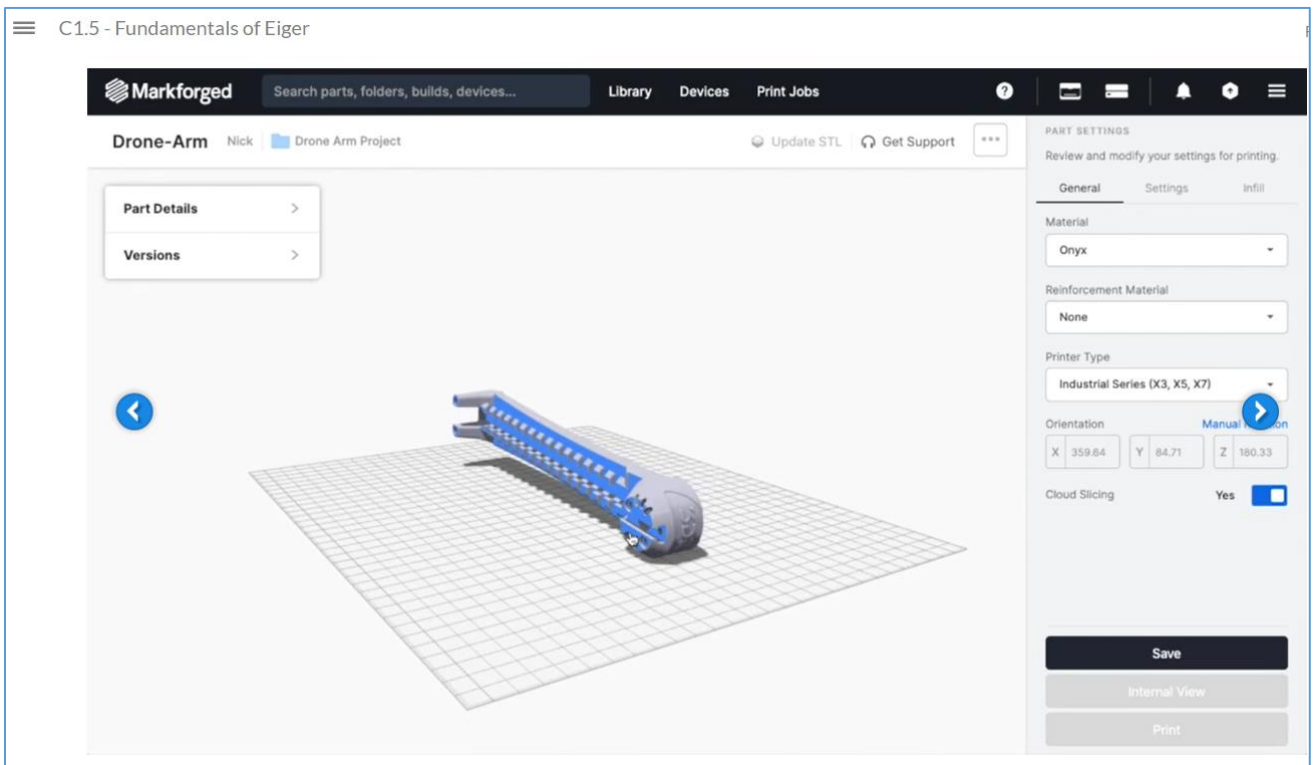
- Manual Orientation.



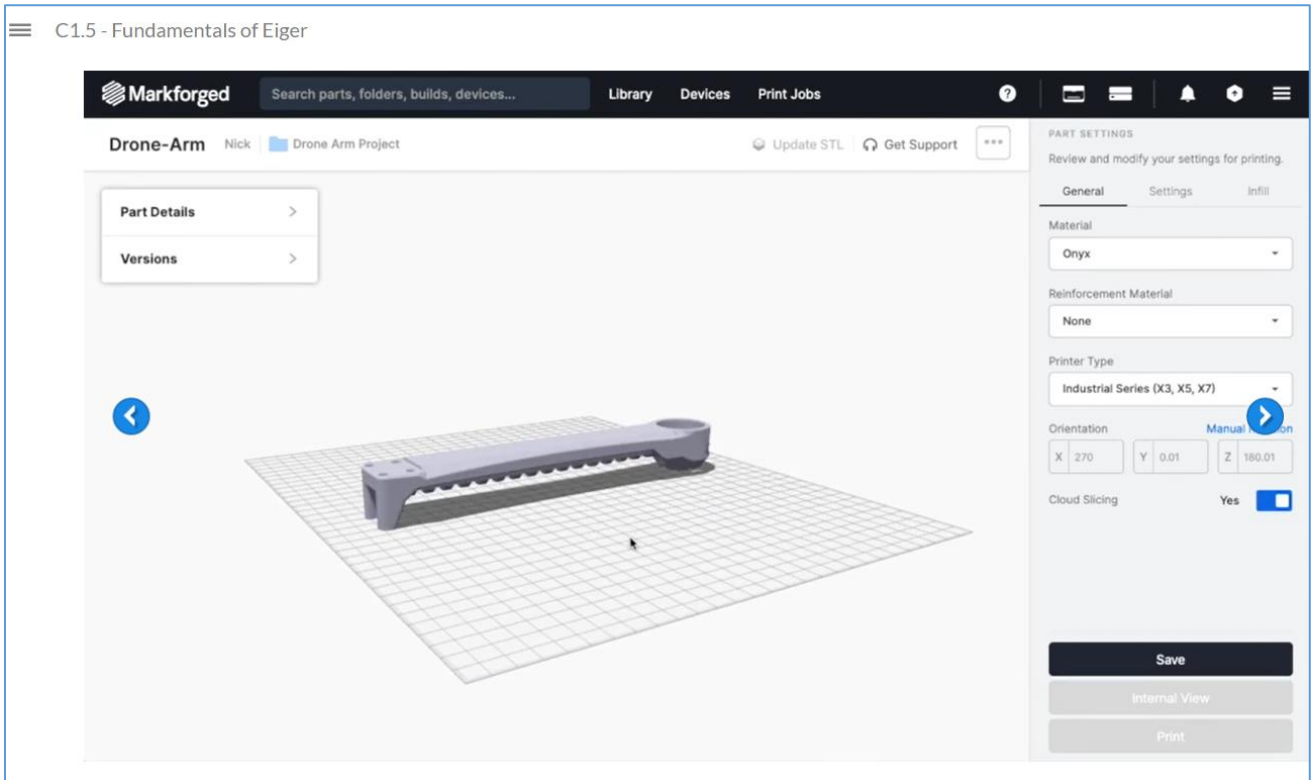
- Or click on surface you want to orientate parallel to.



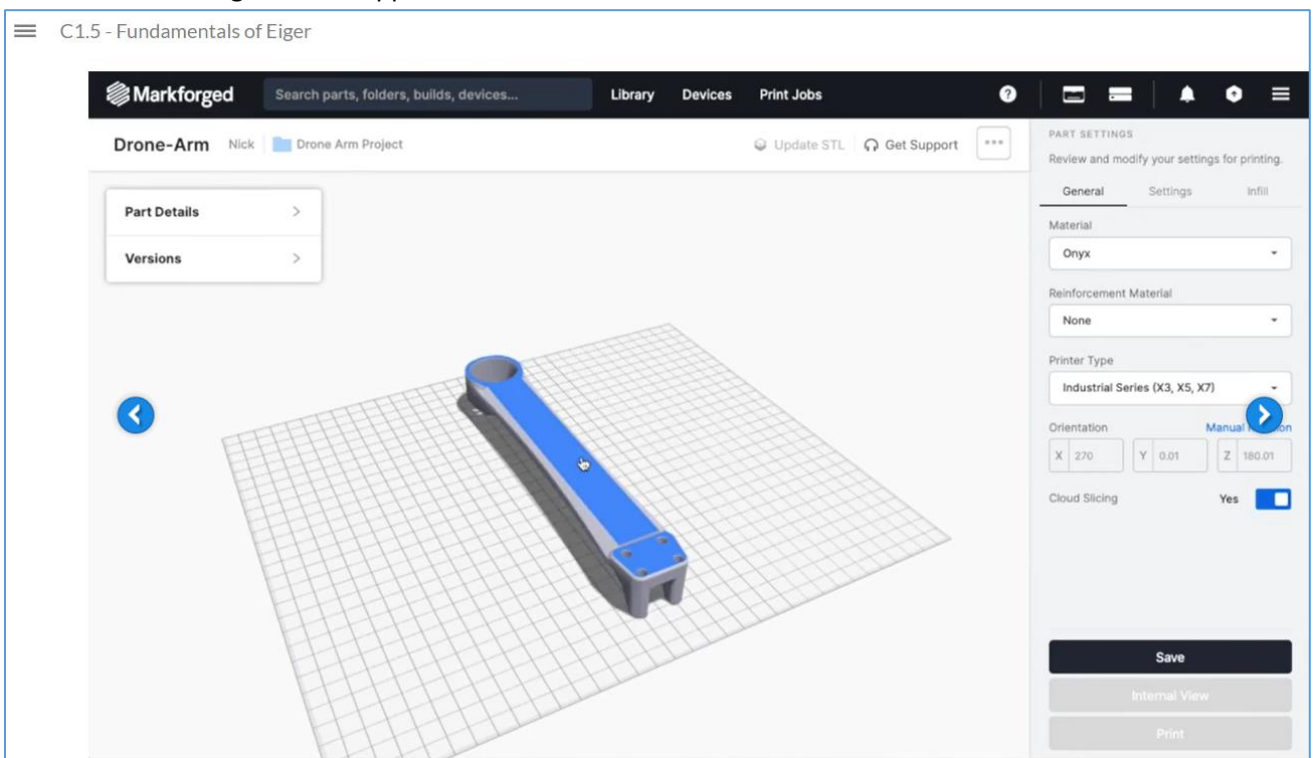
- And the orientated result...



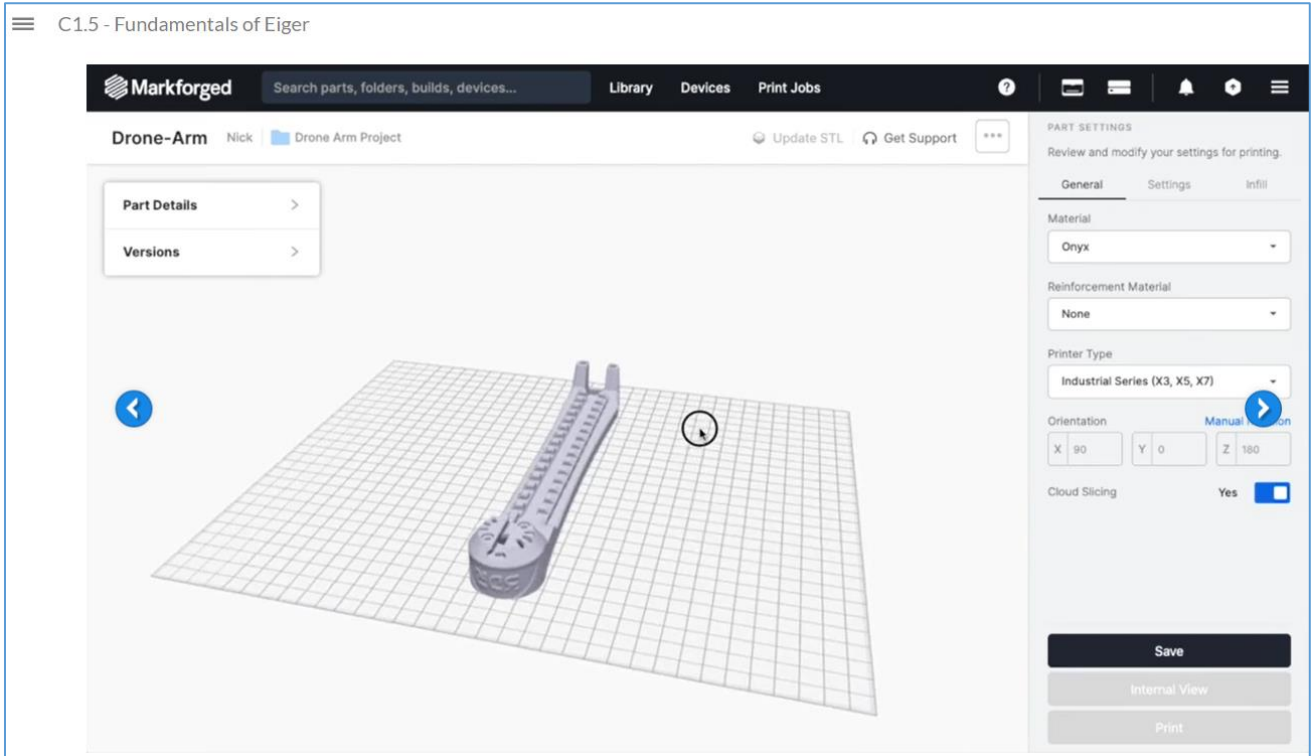
- Another orientation (see high lighted)...



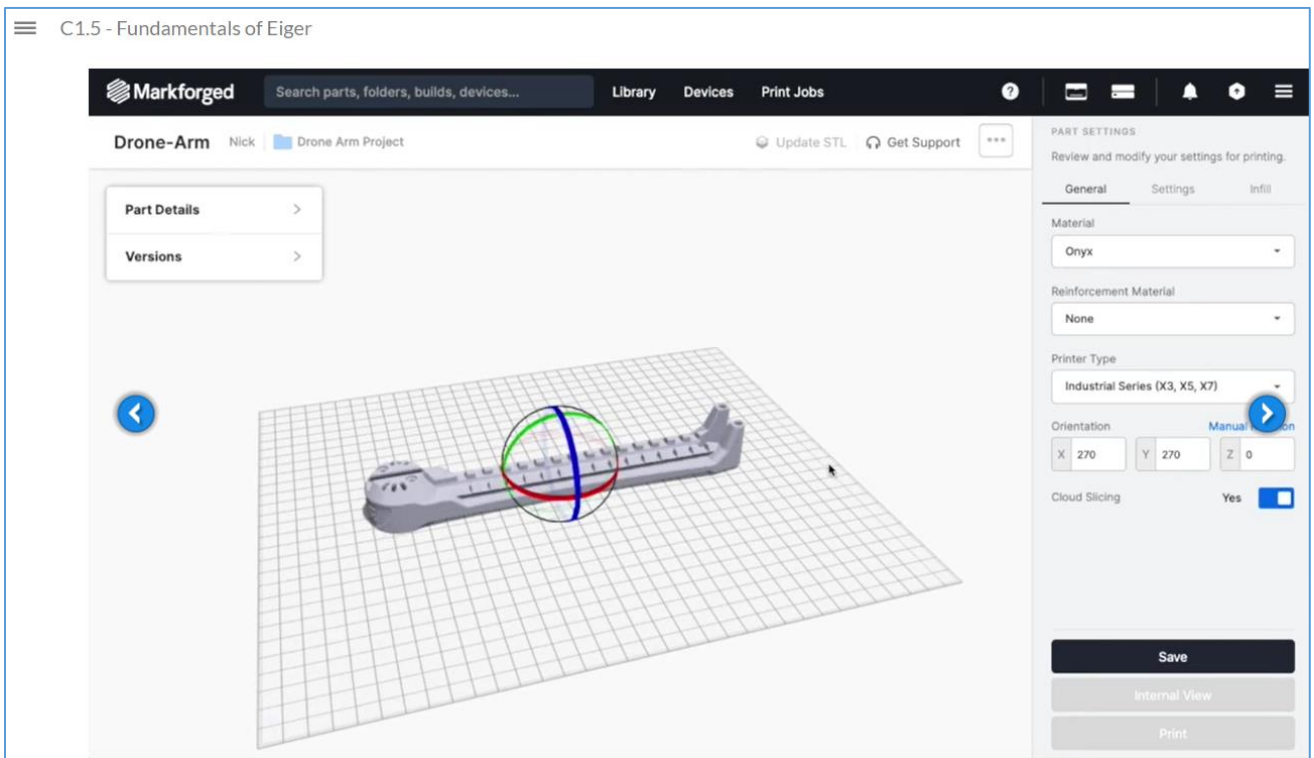
- And the result...
- Disadvantage: Lot of supportmaterial needed.



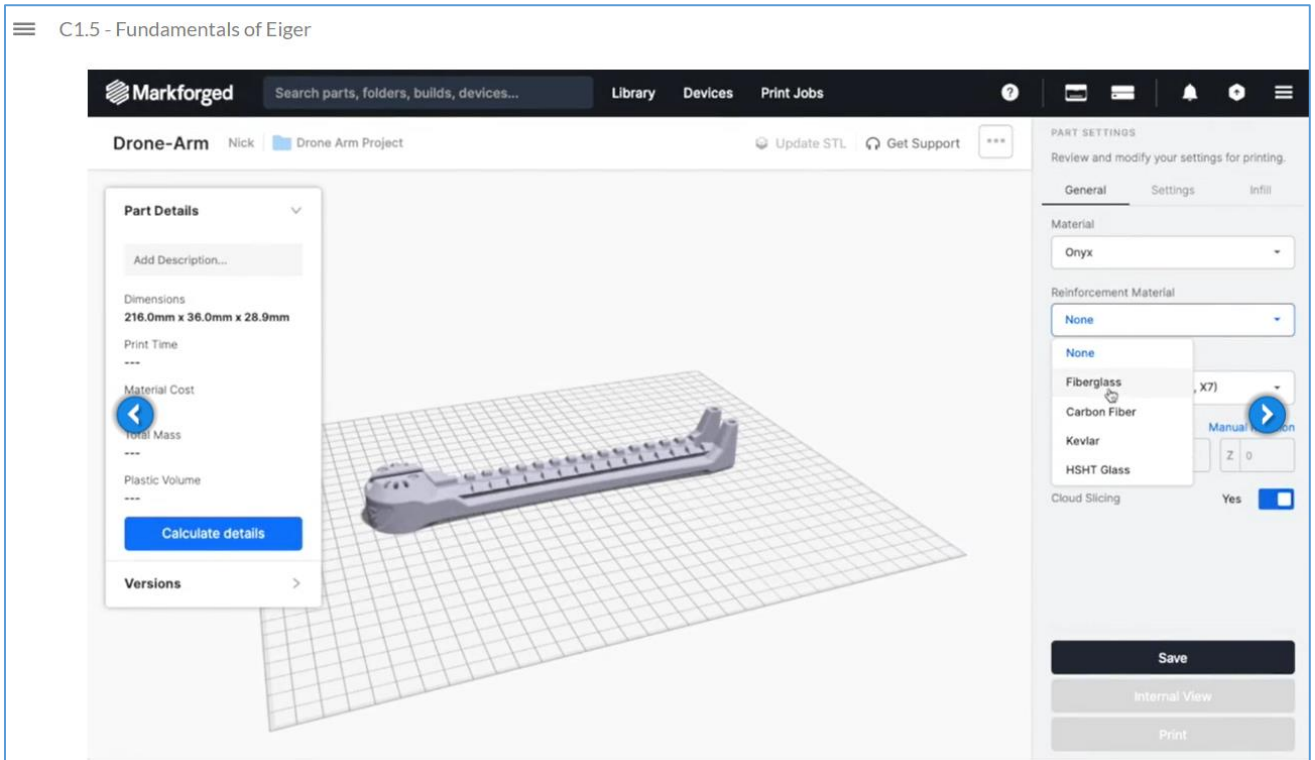
- To choose Opposite Direction by simply clicking



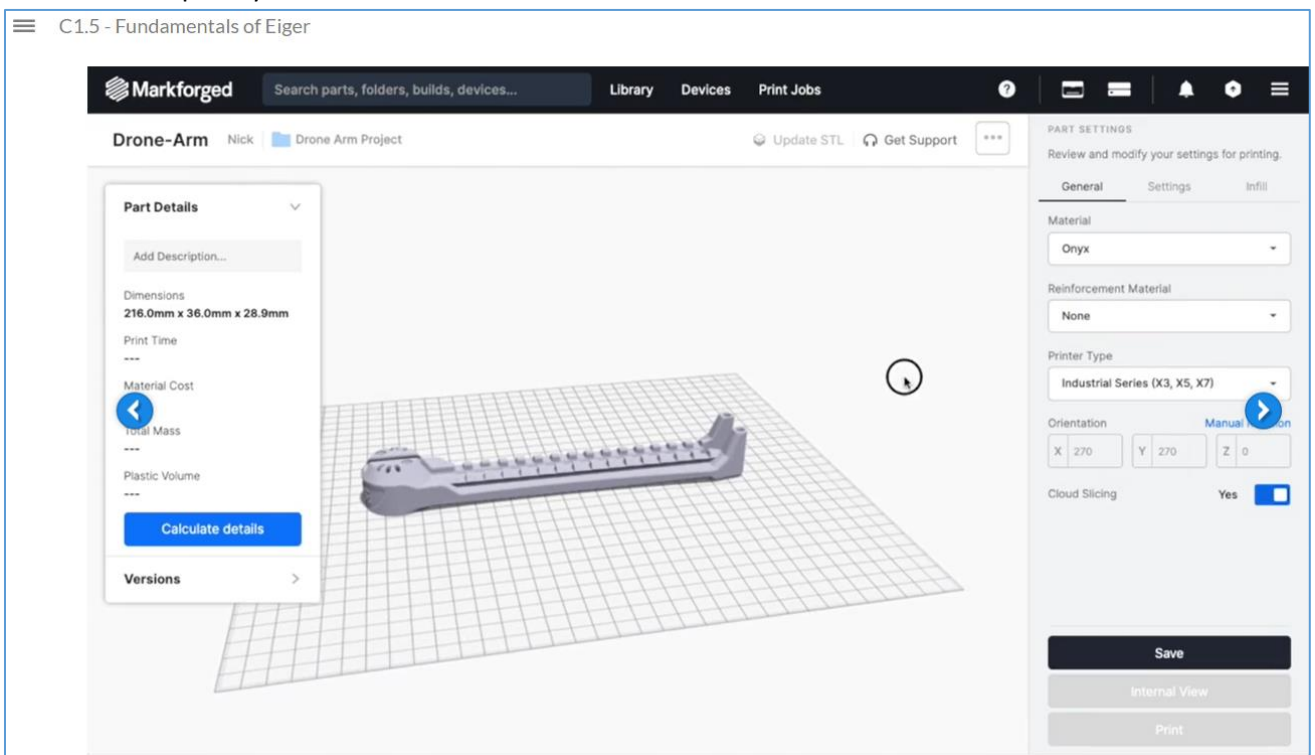
- And the result: Facing down.



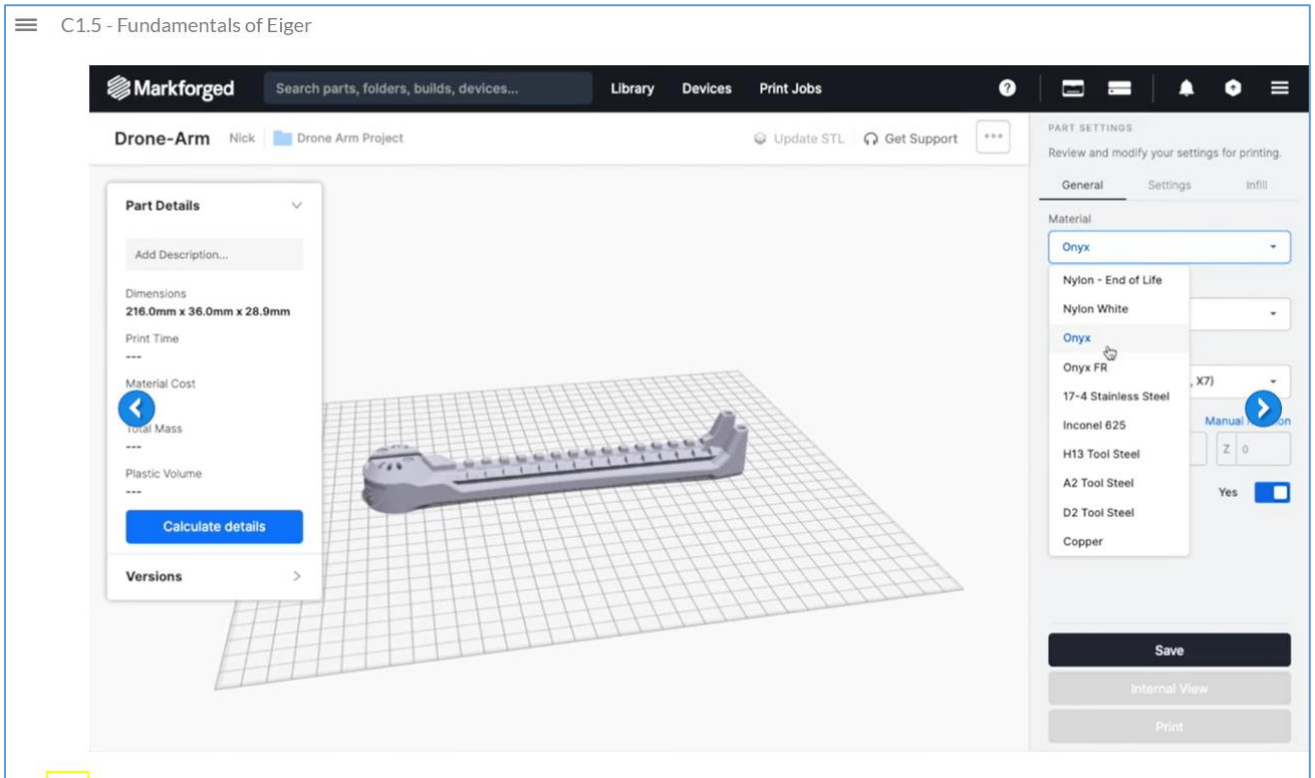




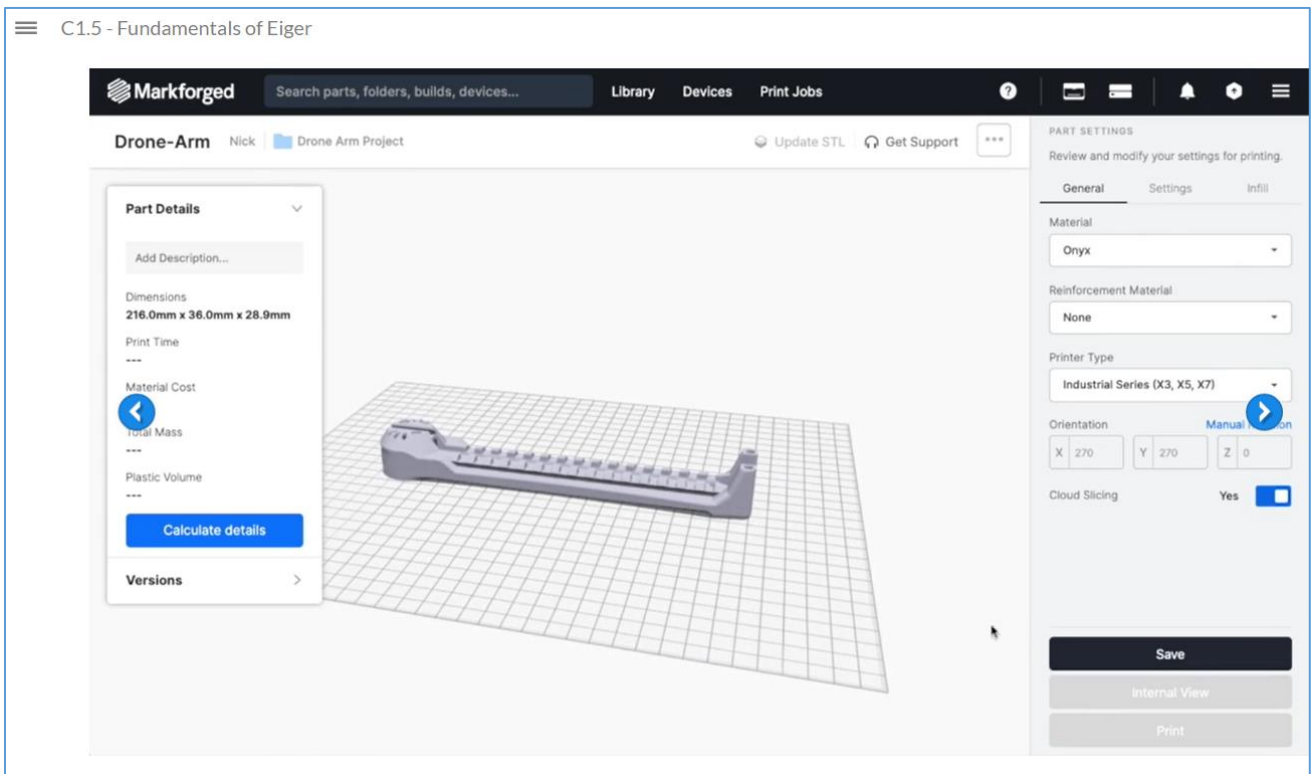
- At this point you can choose Reinforcement Material.



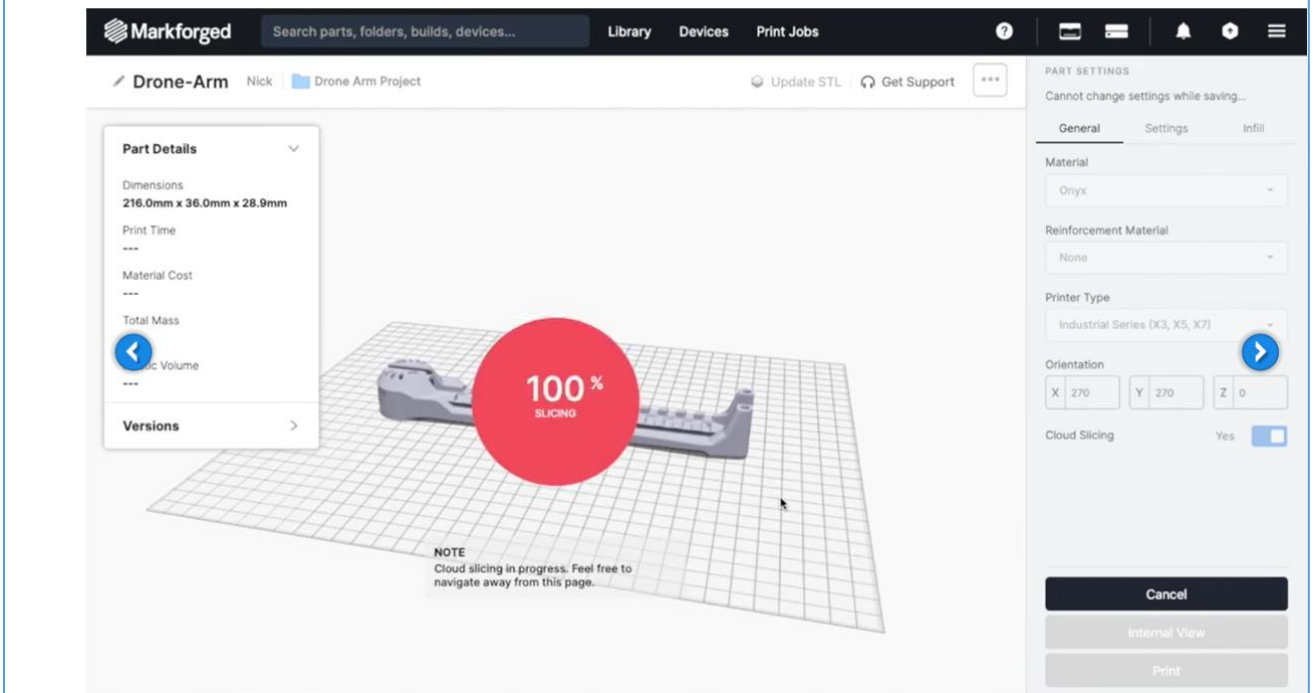
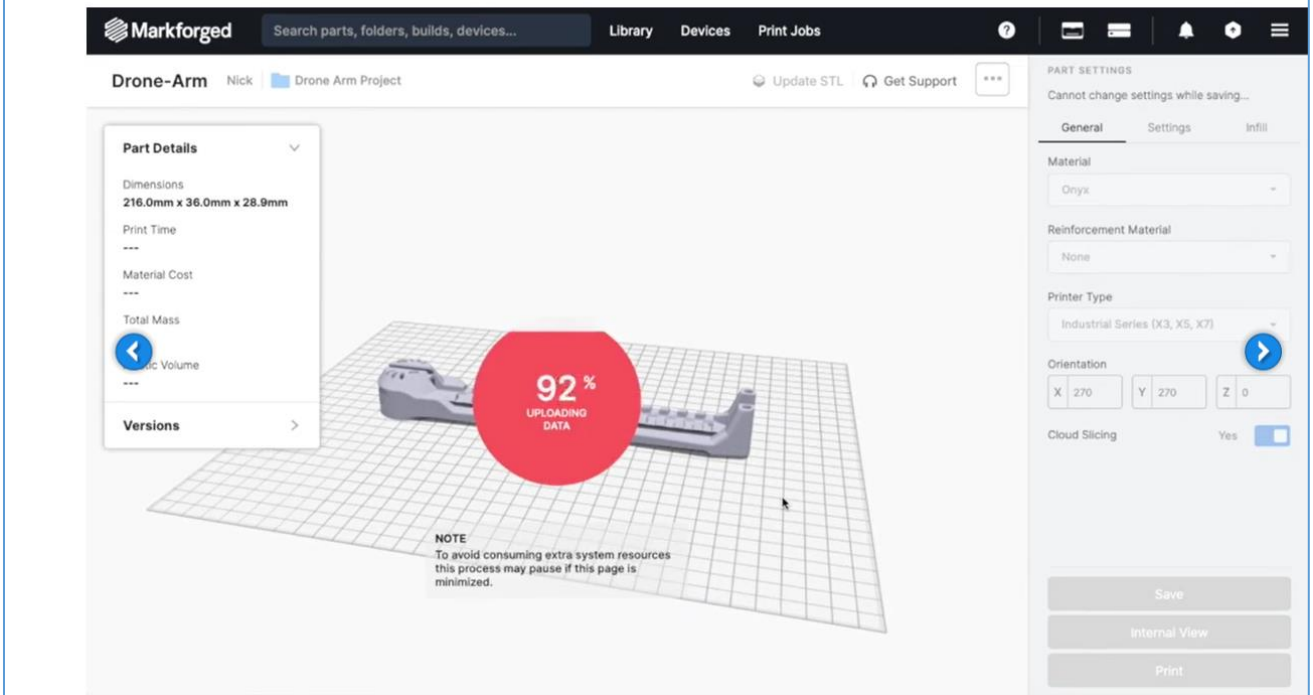
- In this case we use only Onyx Material.



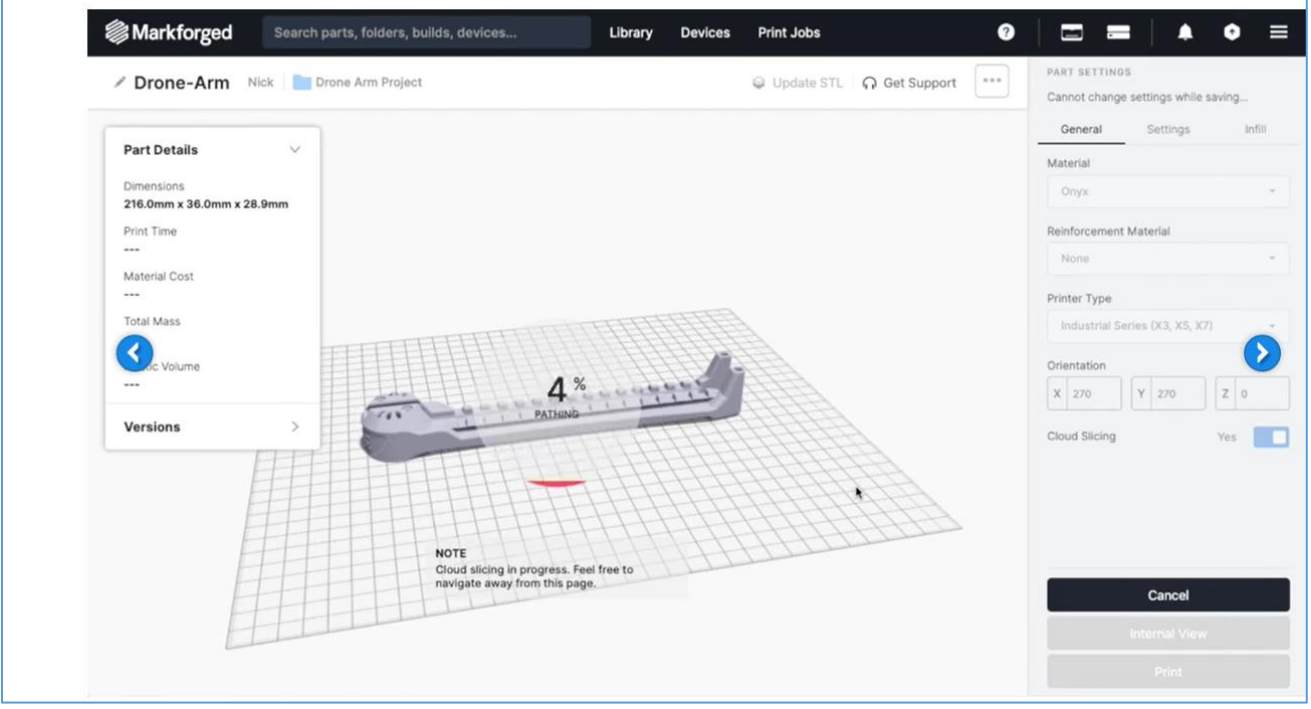
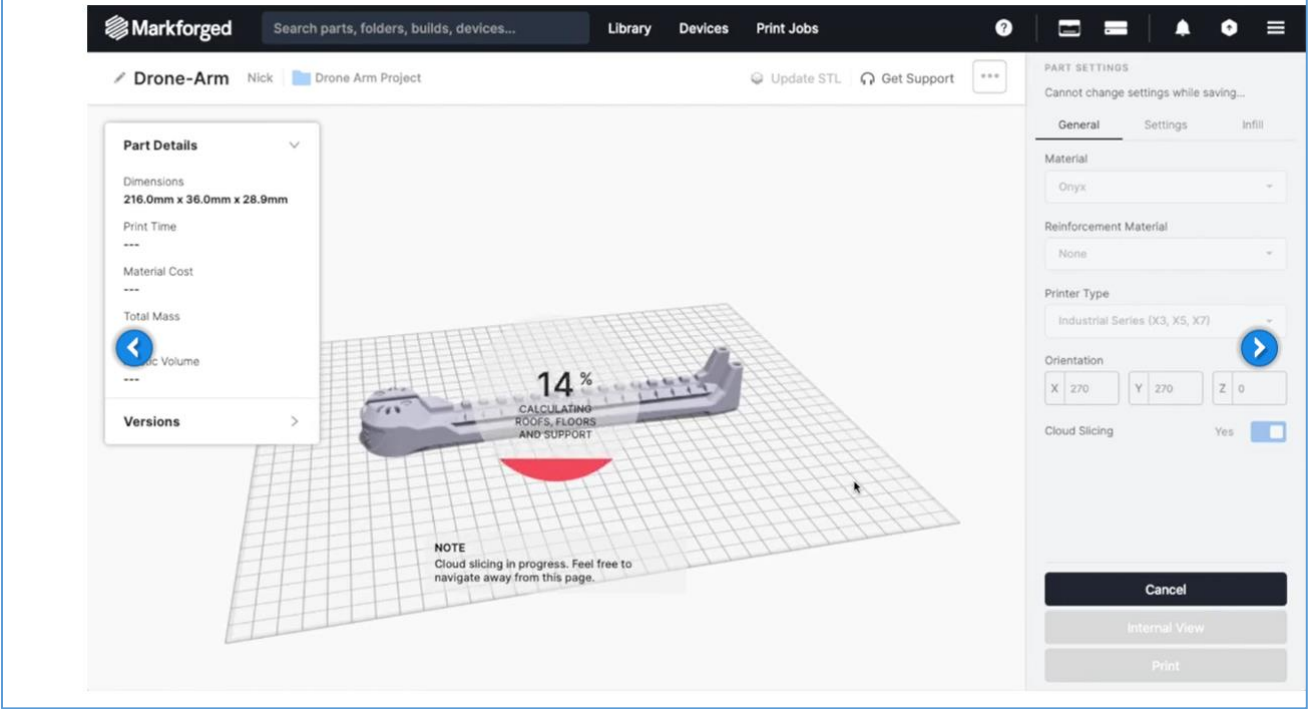
- In this case Onyx Material.

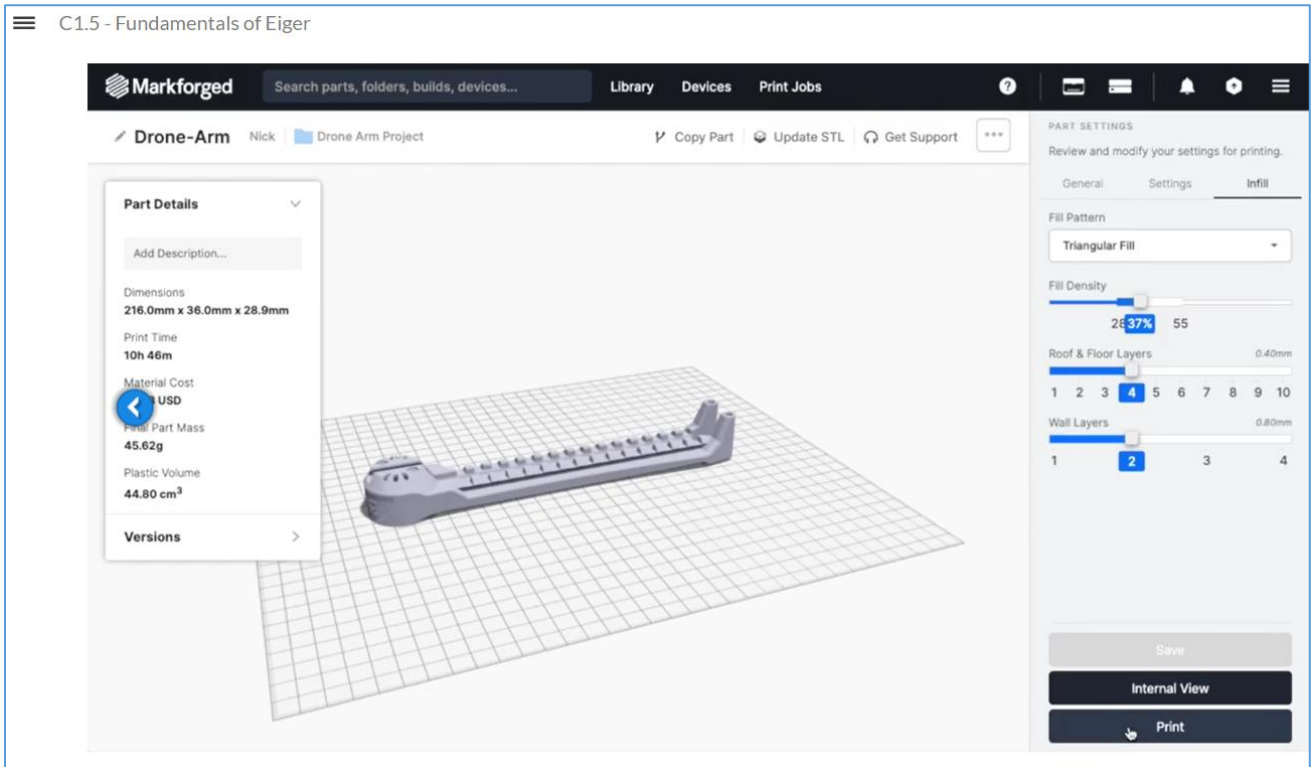


- Save this Configuration.

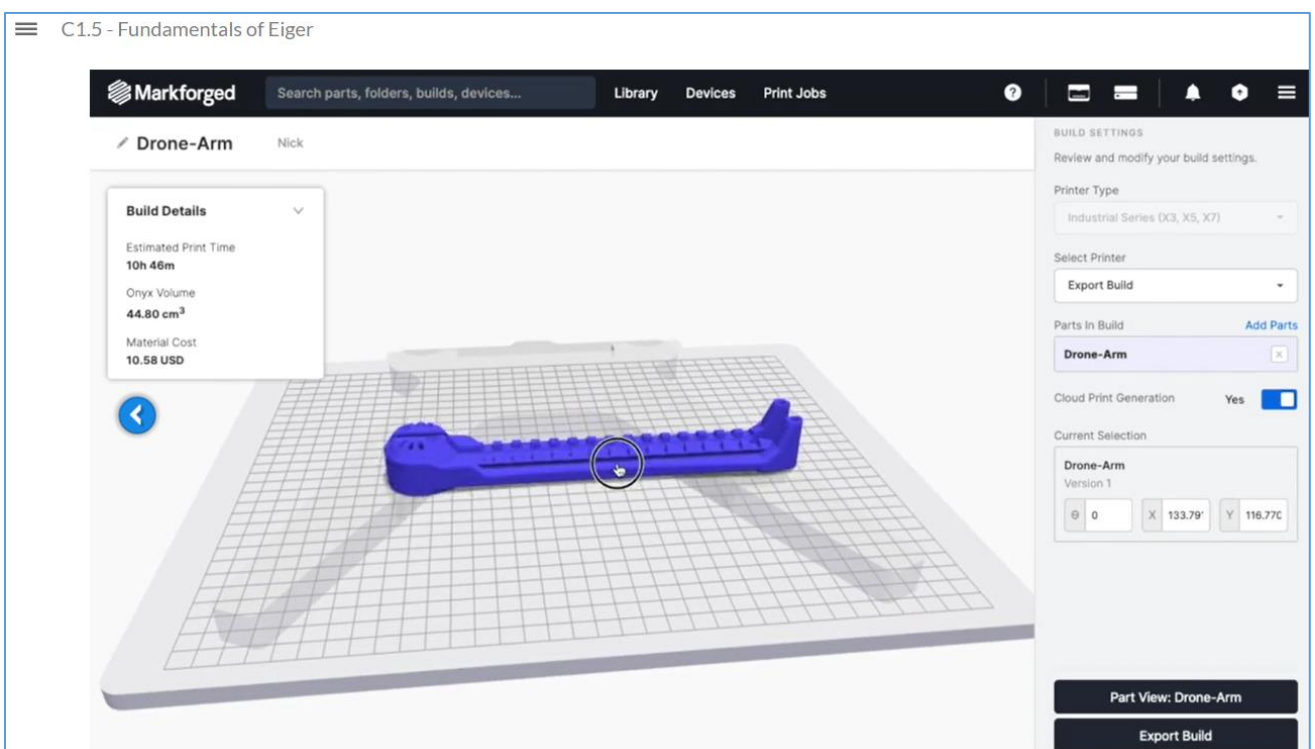


- Slicing.



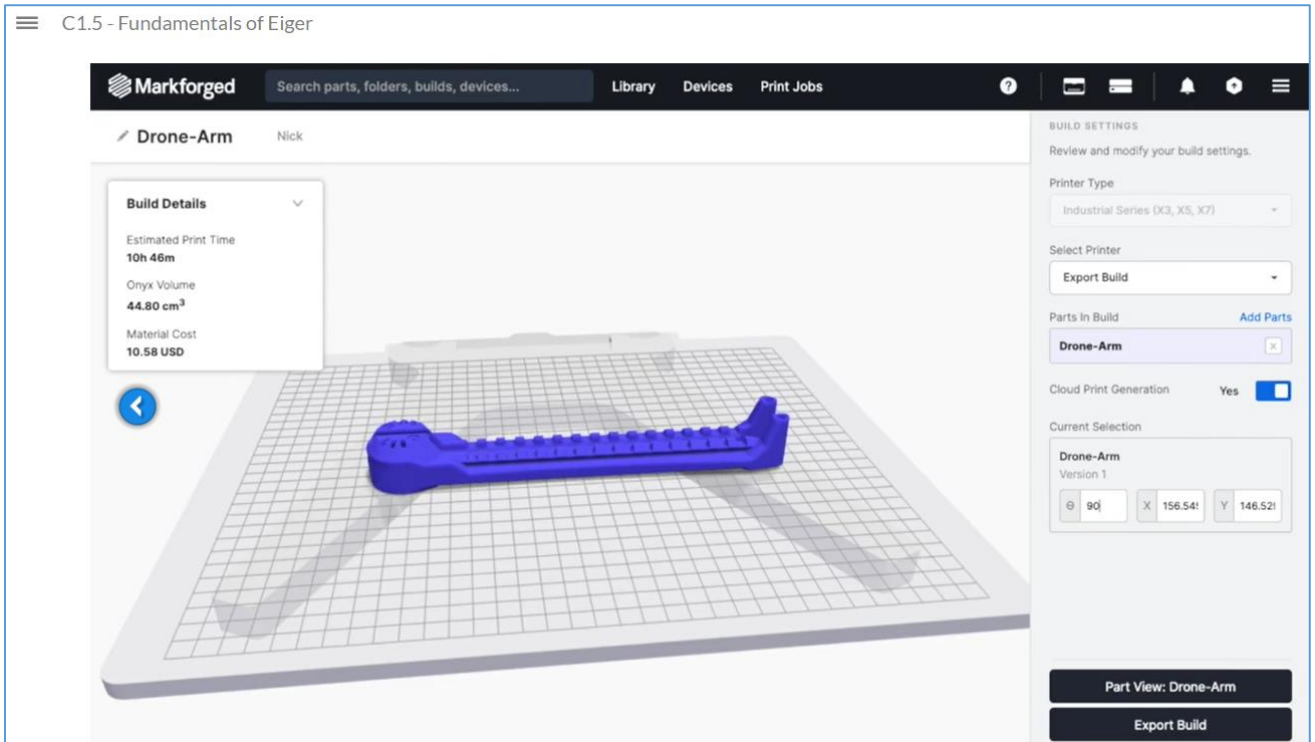


- Print the Drone Arm.

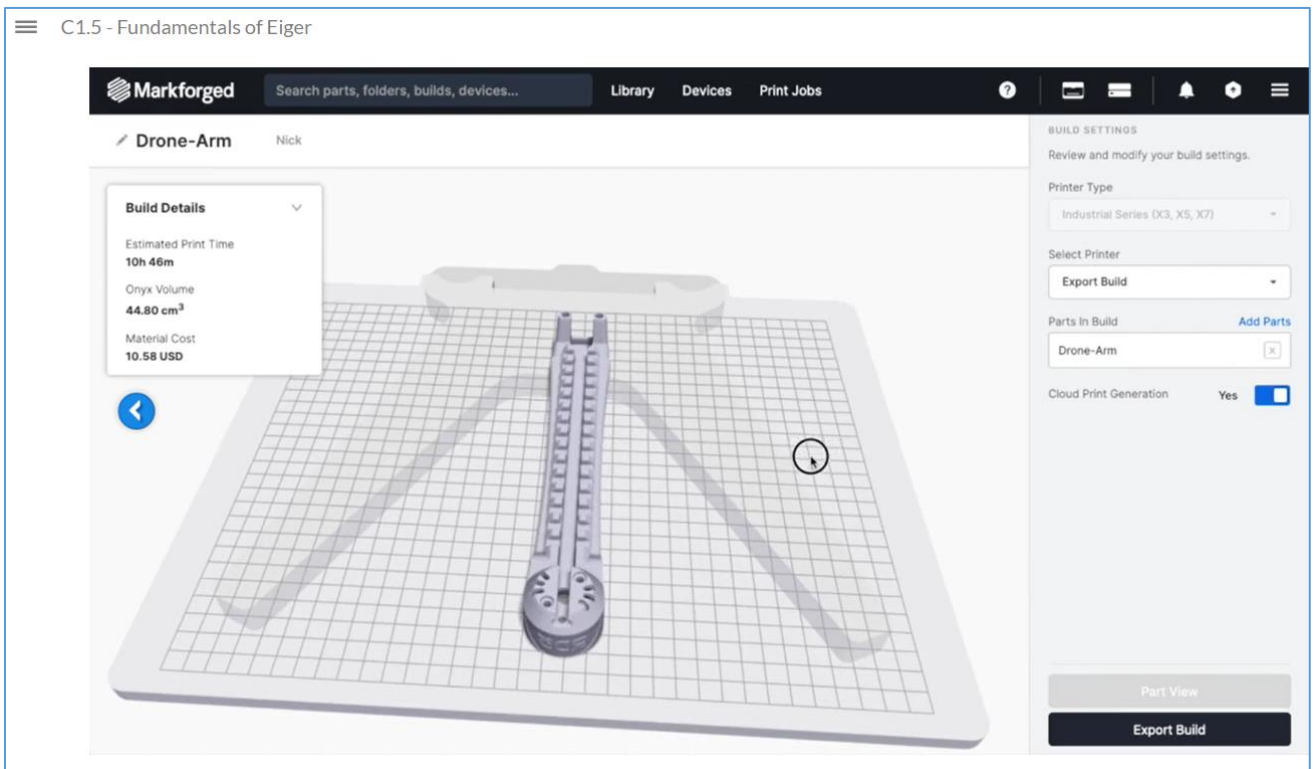


- Click and drag it for replacement on the printed.

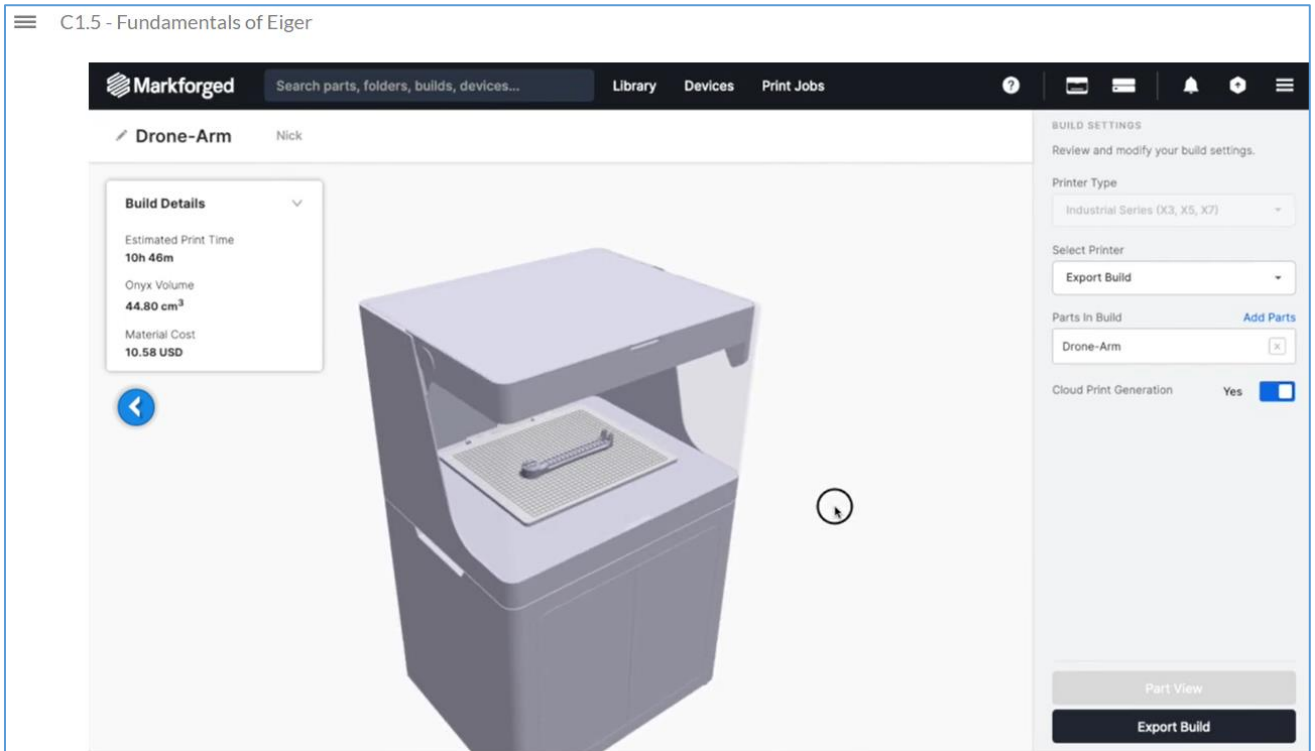




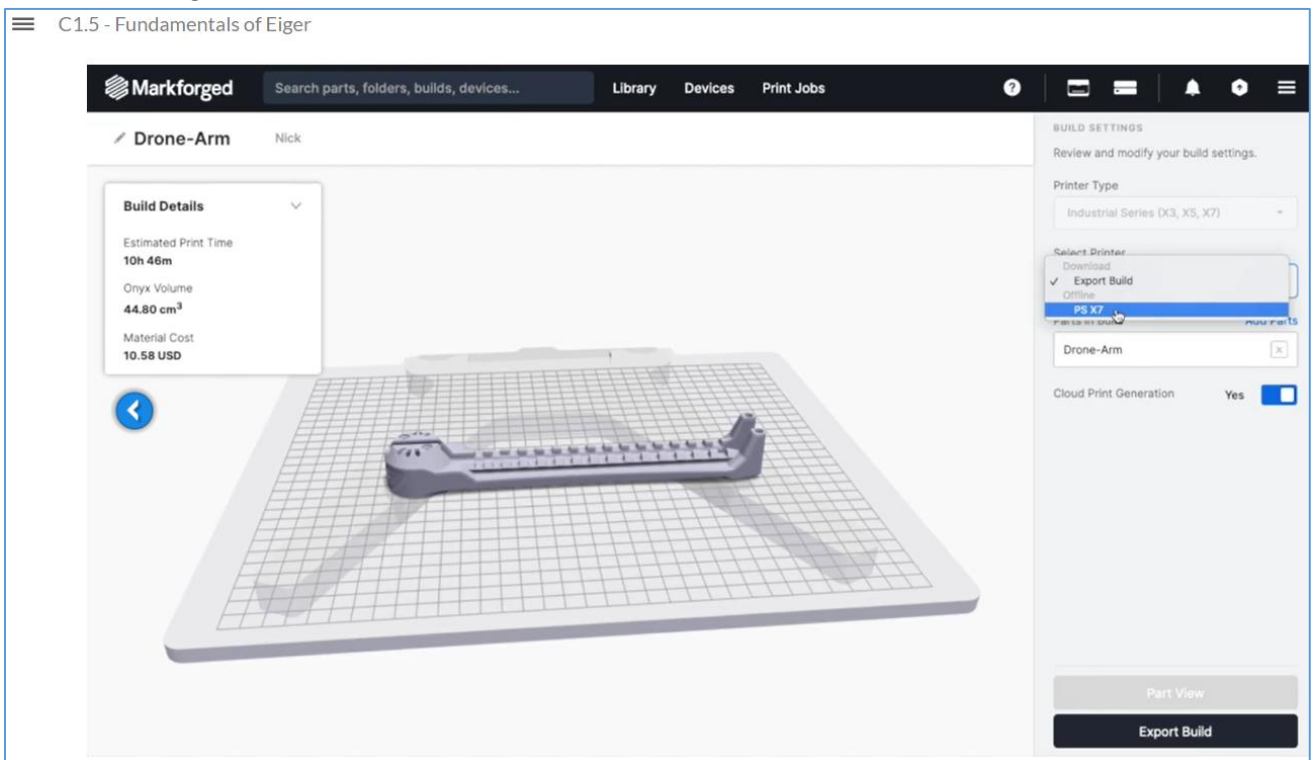
- Manually enter a value.



- And the result of 90 degrees turning.

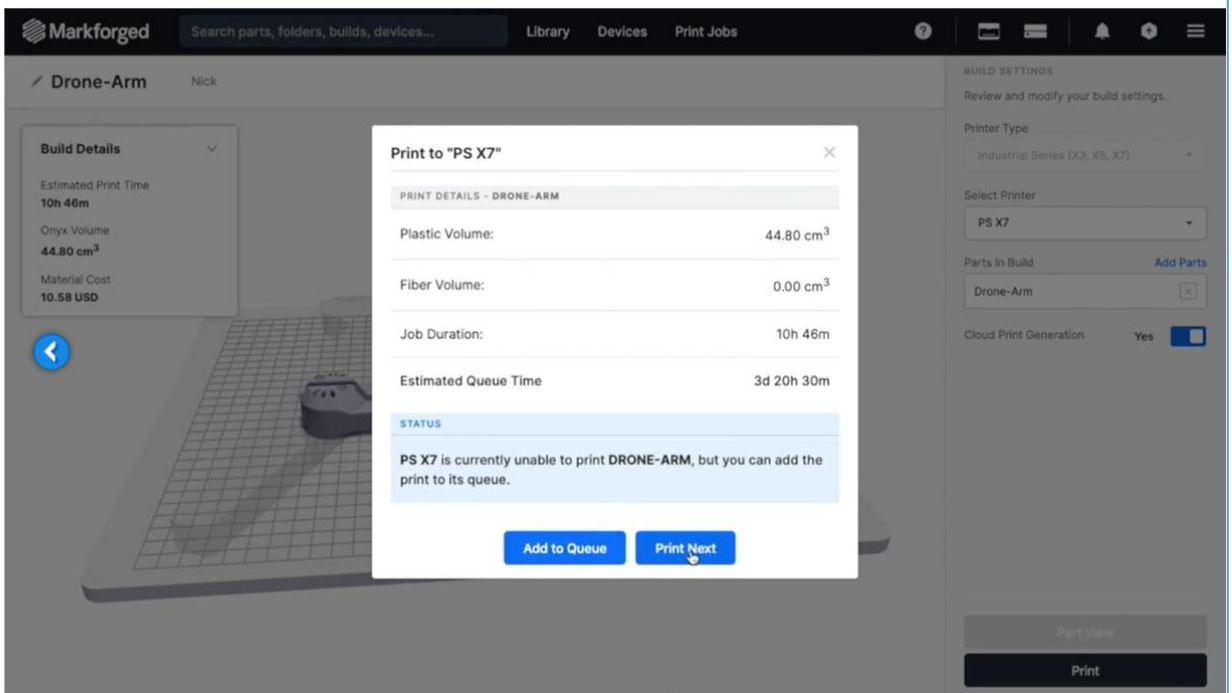
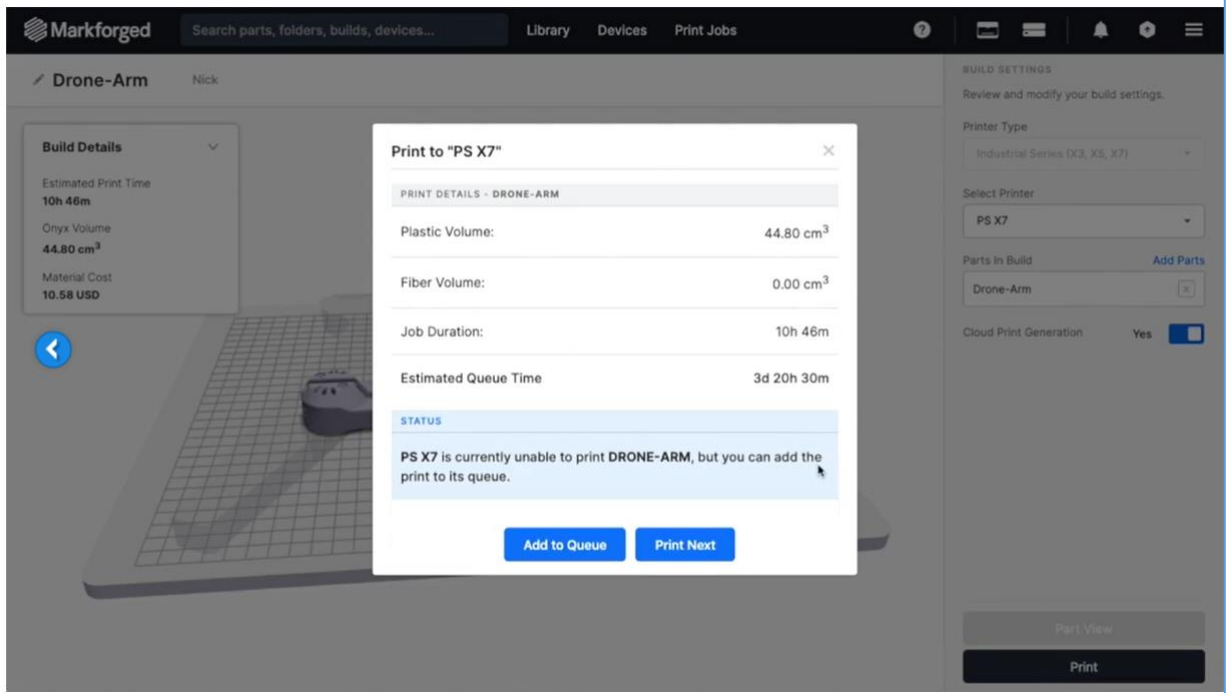


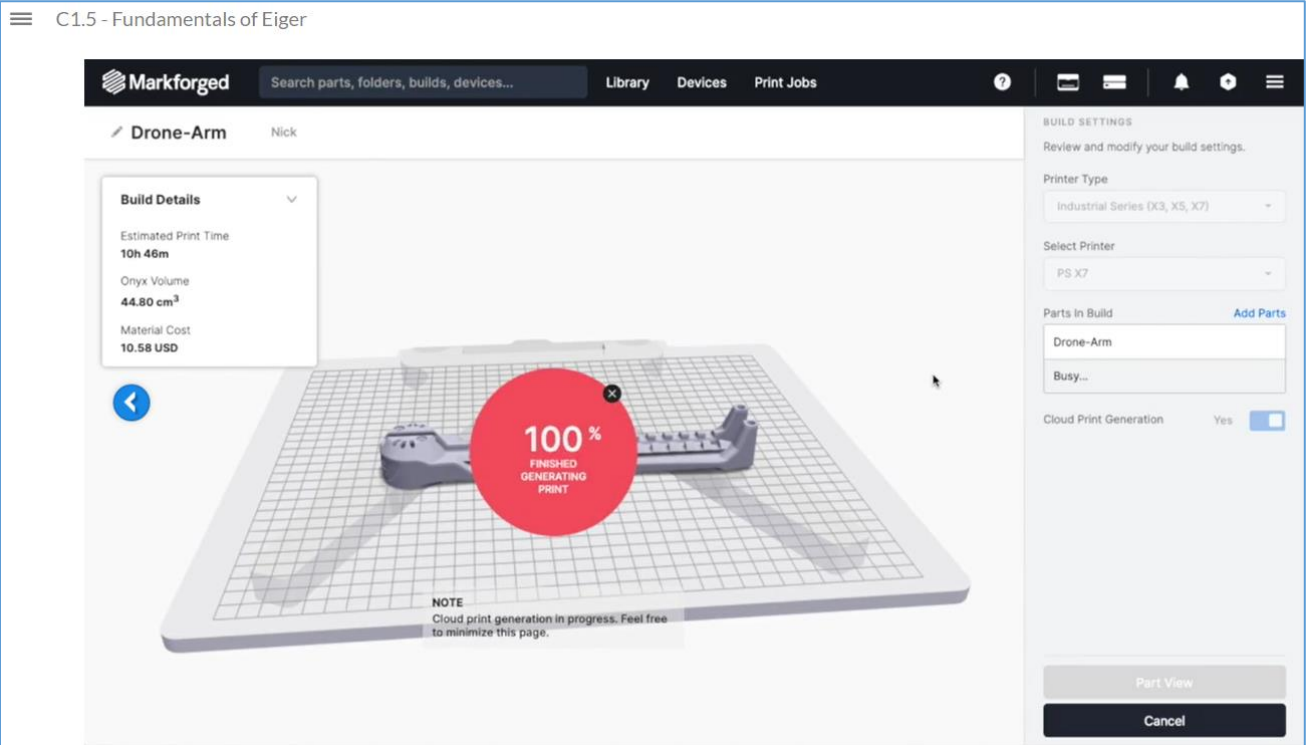
- Zooming In and Out.



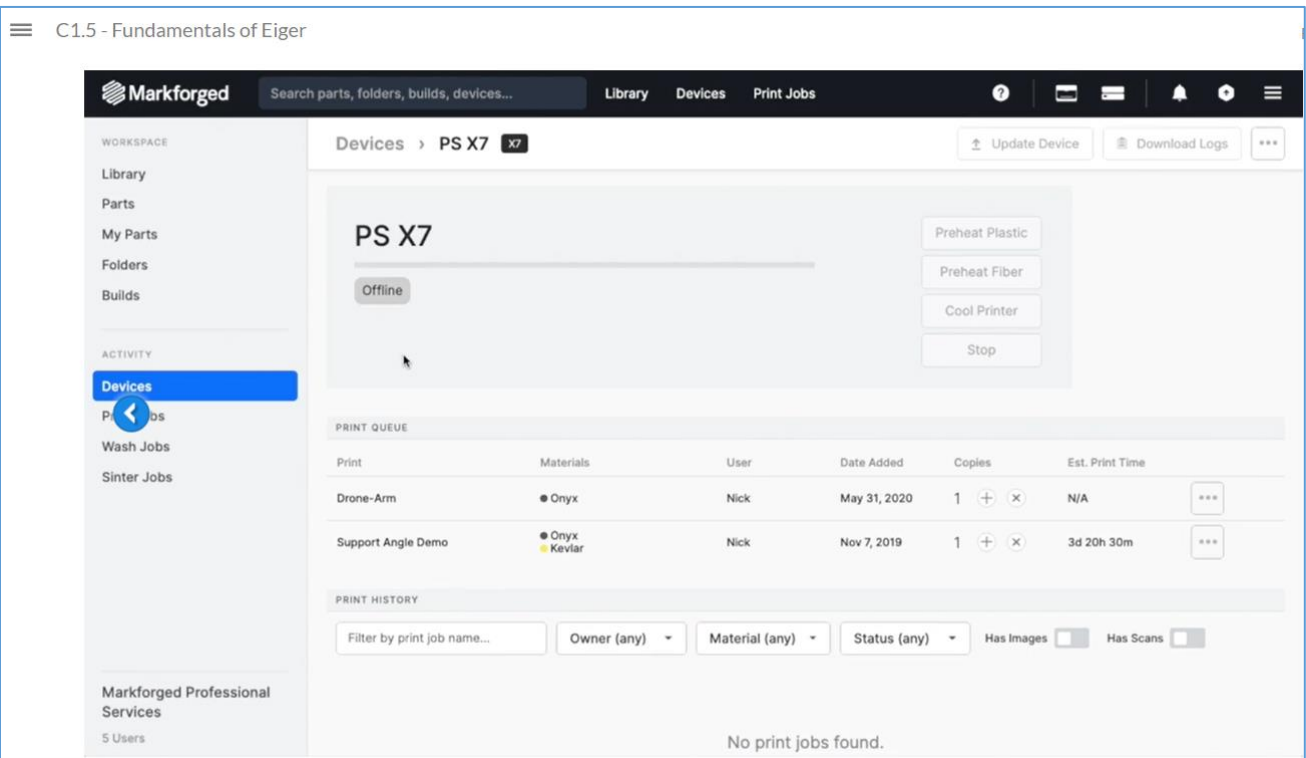
- Selecting the Printer you want to use.

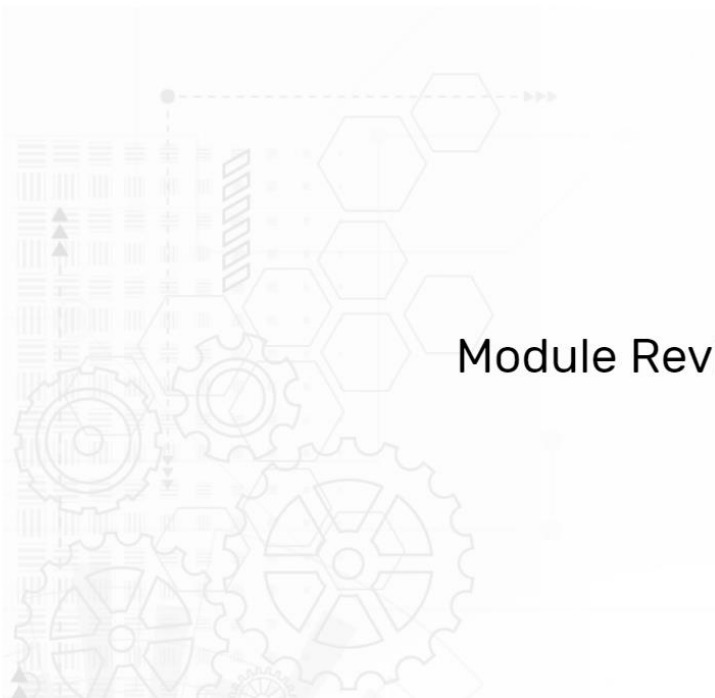






- After "Printing Next"





## Module Review

- **Model Review**

Place the following steps in order for the CAD-to-part workflow of a CFF-reinforced 3D printed part.

1. Export the part as an STL and import it into Eiger
2. Sit back and relax while your part prints!
3. Orient the part and configure its materials and fiber layout
4. Design a part in CAD
5. Slice the part and send a print to an available 3D printer

Place the following steps in order for the CAD-to-part workflow of a CFF-reinforced 3D printed part.

1. Design a part in CAD
2. Export the part as an STL and import it into Eiger
3. Orient the part and configure its materials and fiber layout
4. Slice the part and send a print to an available 3D printer
5. Sit back and relax while your part prints!

Place the following steps in order for the CAD-to-part workflow of a CFF-reinforced 3D printed part.


1. Design a

2. Export the

3. Orient the

4. Slice the

5. Sit back a



Correct

That's right! You selected the correct response.

Continue

The screenshot shows the Markforged Eiger interface. The top navigation bar includes the Markforged logo, a search bar, and links for Library, Devices, and Print Jobs. A left sidebar lists workspace categories like Library, Parts, My Parts, Folders, and Builds, as well as activity categories like Print Jobs, Wash Jobs, and Sinter Jobs. The main area displays a table of devices with columns for name, part, device group, status, progress, printer, and queue. A dark overlay at the bottom contains the text: "Navigate back to the library by clicking any link that would take you there in Eiger".

Device	Part	Group	Status	Progress	Printer	Queue
Mark Two	House Sparrow	Default Device Group	Print Paused	1h 29m	Printer	No Queue
X7	Mark X Copilot	Default Device Group	Printing	16h 52m	Printer	No Queue
X7	Mark X Demo Printer	Default Device Group	Printing	17h 00m	Printer	No Queue
Metal X	Metal XD	Default Device Group	Out of Material		Printer	No Queue
Metal X	Mjolnir	Default Device Group	Print Paused	1d 07h 46m	Printer	No Queue
Mark Two	Mr. Wahiberg	Default Device Group	Printing	34m	Printer	No Queue
Metal X	Nebuchadnezzar	Default Device Group	Printing	1d 07h 23m	Printer	No Queue
Mark Two	Nefertiti	Default Device Group	Print Paused		Printer	No Queue
Mark Two	Old Guy	NPM Swab Campaign	Printing	1h 36m	Printer	No Queue
Mark Two	Roadgast The Brown	Default Device Group	Printing	4h 52m	Printer	No Queue

The screenshot shows the Markforged Eiger interface with a confirmation dialog box overlaid. The dialog box features a green checkmark icon, the word "Correct", and the message "That's right! That will bring you back to the library!". A "Continue" button is located at the bottom of the dialog. A dark overlay at the bottom contains the text: "Navigate back to the library by clicking any link that would take you there in Eiger".

## Check all that can be contained in an Eiger Organization

- CFF filament spools
- CNC machining centers
- Teams (Enterprise Eiger only)
- Print history data
- Oriented and configured parts
- Printers
- Users

## Check all that can be contained in an Eiger Organization

- CFF filament spools
- CNC mach
- Teams (En
- Print histo
- Oriented a
- Printers
- Users



Correct

That's right! All of these are things that are part of an Eiger Organization.

Continue

Which is a role that Eiger plays in the 3D printing process?

- Print preparation – including orientation, material configuration and slicing
- Printer management and fleet analytics
- Remote monitoring and print queue control
- All of the above

Which is a role that Eiger plays in the 3D printing process?

- Print preparation – including orientation, material configuration and slicing
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- All of the above

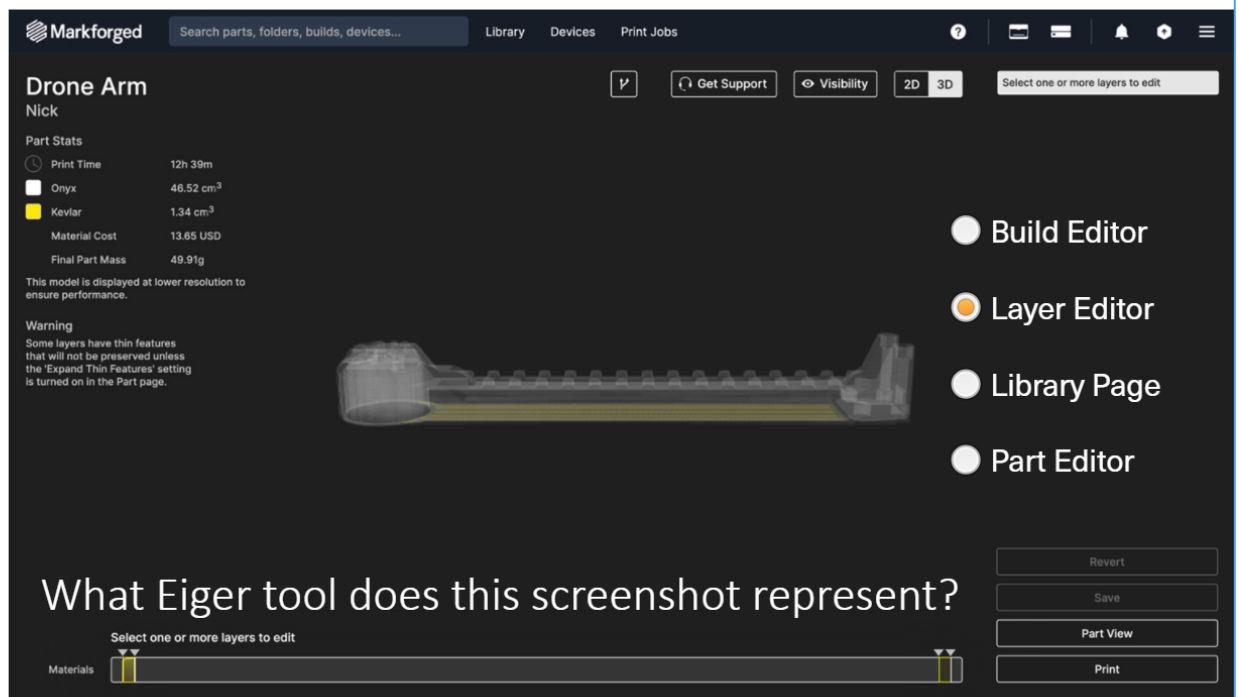


Correct

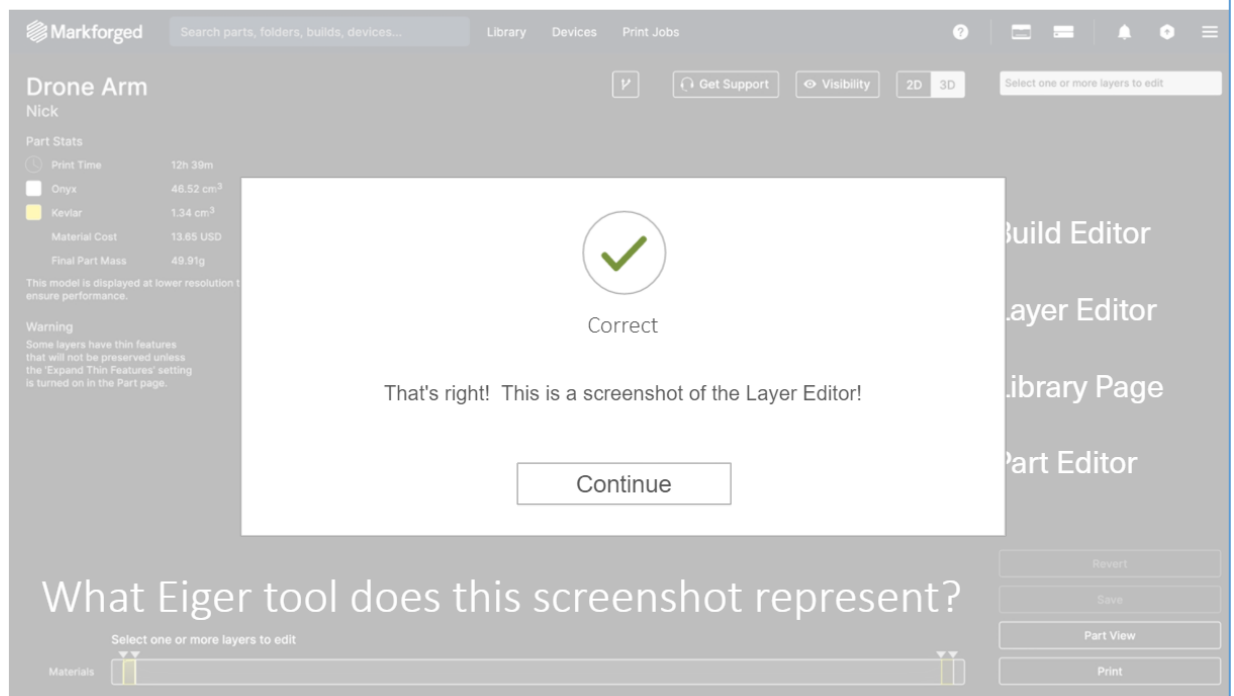
That's right! You selected the correct response.

Continue





What Eiger tool does this screenshot represent?



What Eiger tool does this screenshot represent?

## Results

Your Score: 100% (50 points)  
Passing Score: 80% (40 points)

---

### Result:



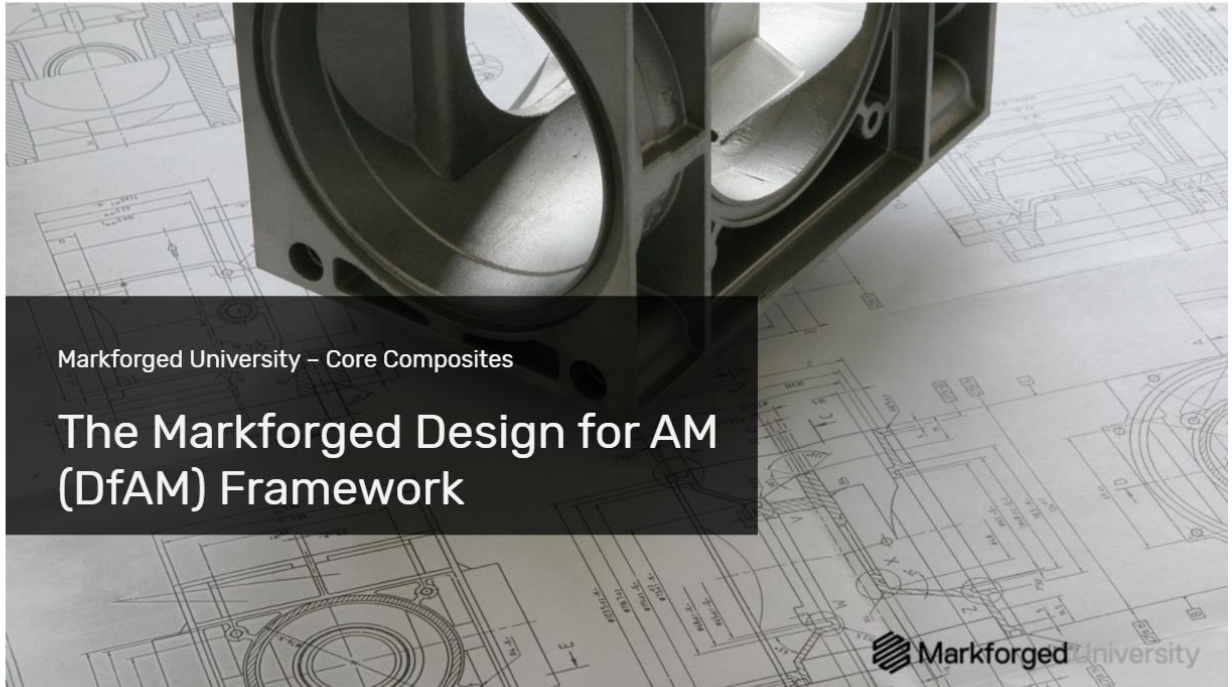
Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

## C.1.6. The Markforged Design for AM (DfAM) Framework

☰ C1.6 - The Markforged Design for AM (DfAM) Framework



- AM = [Additive Manufacturing](#)

☰ C1.6 - The Markforged Design for AM (DfAM) Framework

## Module Overview

Intro to the Markforged DfAM Framework

Case Study: Dixon Valve and Coupling Co.

- Business Challenge
- Technical Hurdles
- Result and ROI

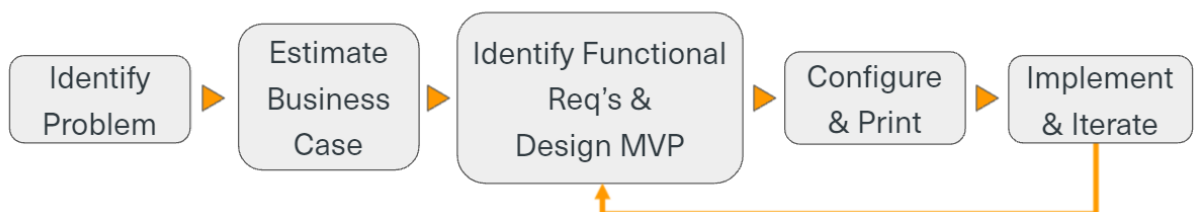
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- **Model overview**

## How do we think about design for the FFF+CFF processes?

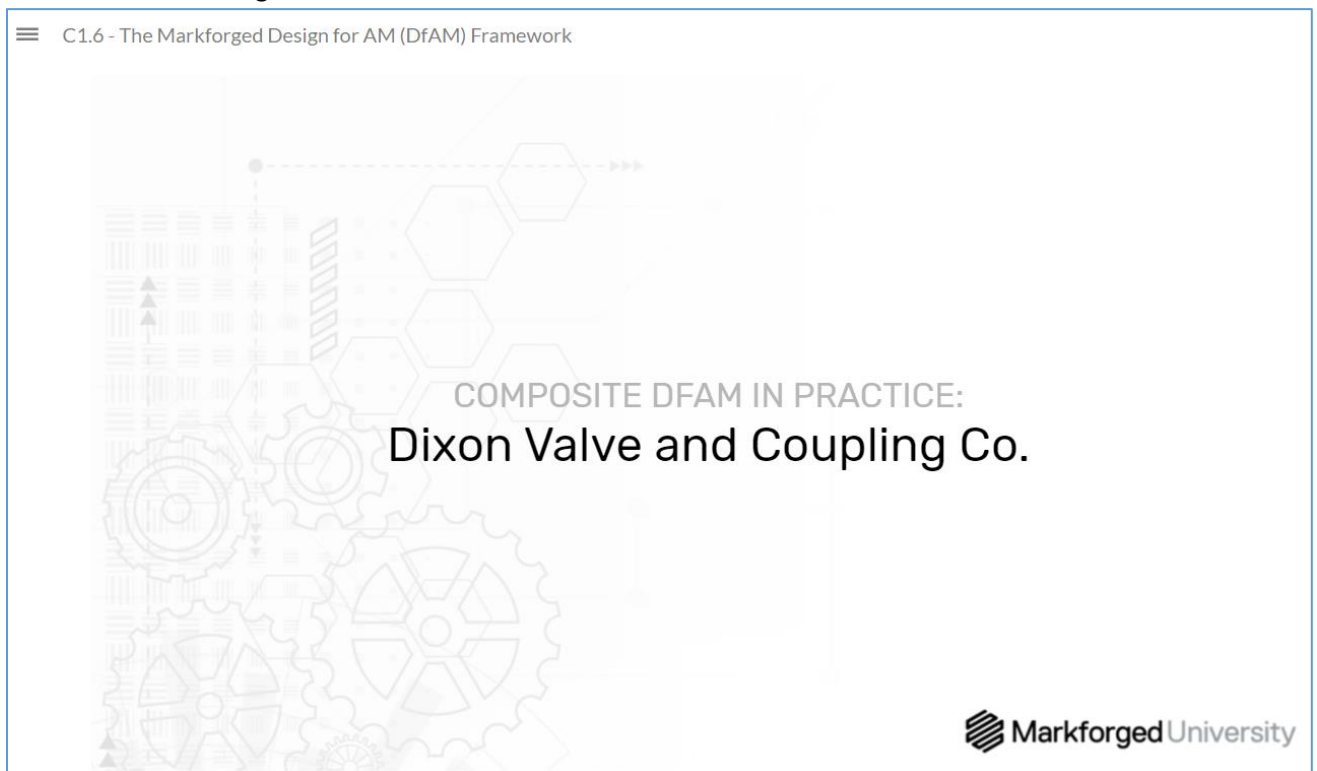
- **How do we think about design for the FFF+CFF processes?**

## Markforged Design for AM Framework



- **Markforged Design for AM Framework**

- Identify Problem: Bijvoorbeeld een onderdeel in een fabricageproces wat steeds stuk gaat. Je kan hem anders construeren of een beschermbumper of iets dergelijks maken. Dit om down time te verlagen.
- Schatten: Hoeveel heb je er nodig? In 1 keer, of verspreid over langer tijd? Misschien kiezen voor om het onderdeel anders te produceren (stel als er heel veel nodig hebt). Kortom: worden de kosten daadwerkelijk gereduceerd, met het printen van het onderdeel?
- MVP = Minimum viable product. Translate: Minimaal levensvatbaar product.
- Configure and Print: Oriantation? Reinforcement with wich material?
- Implement & Iterate (Iterate = herhalen = sequentieel = opeenvolgend). Als uit (destructieve) test blijkt dat het onderdeel bijvoorbeeld te zwak is: opnieuw configureren.



- **Markforged Design for AM Framework**

- Example.



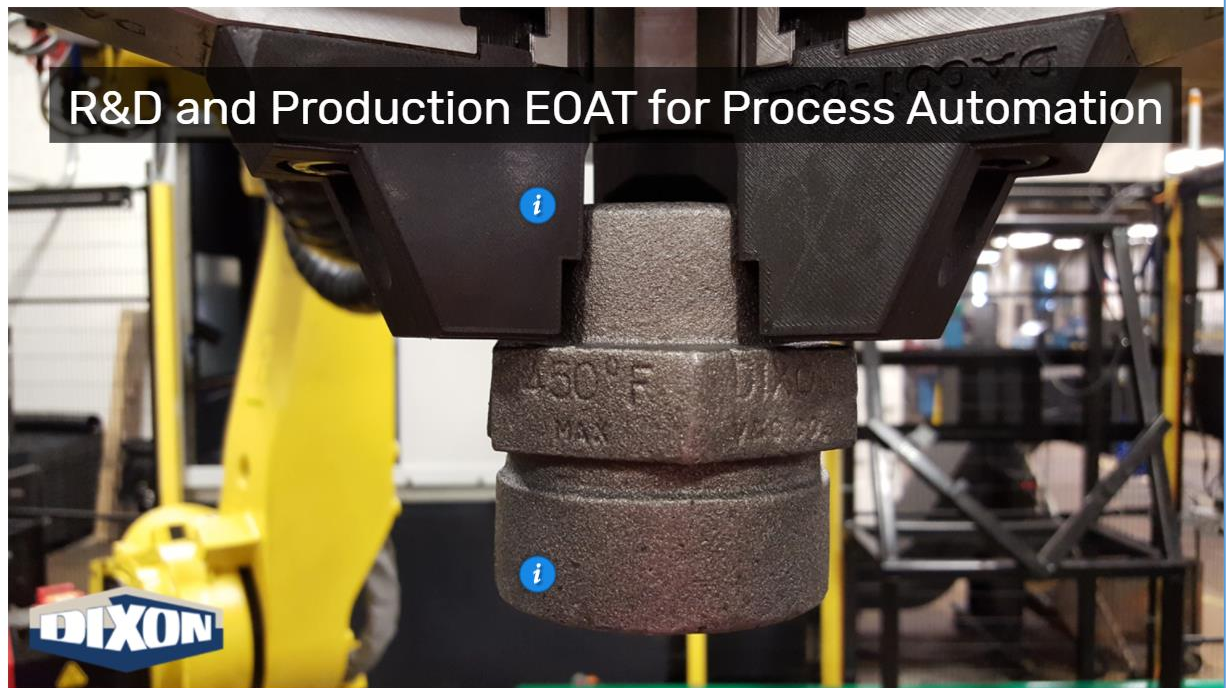
### Dixon Valve and Coupling Co.

100+ year old manufacturer and leader in hose fittings and fluid transfer components

Dixon Advanced Manufacturing Engineering (AME) team drives continuous process improvement and advanced technology adoption

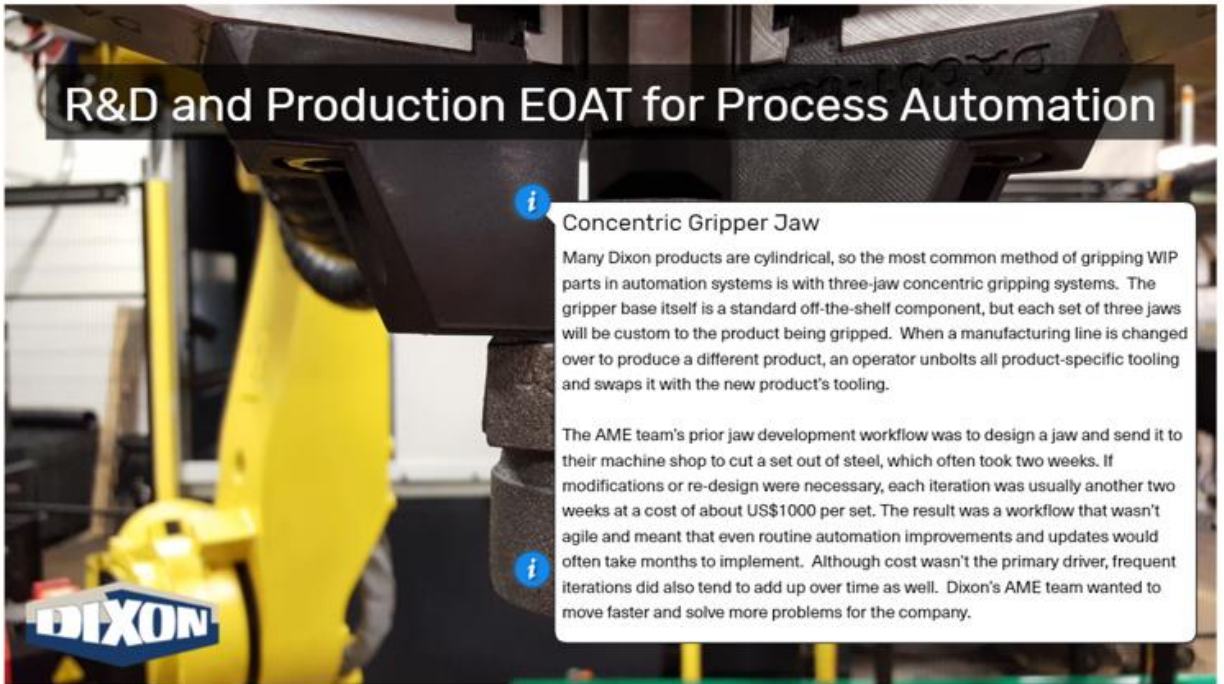


- Dixon valve and the AME-team



- End-of-arm Tooling for Plant Automation





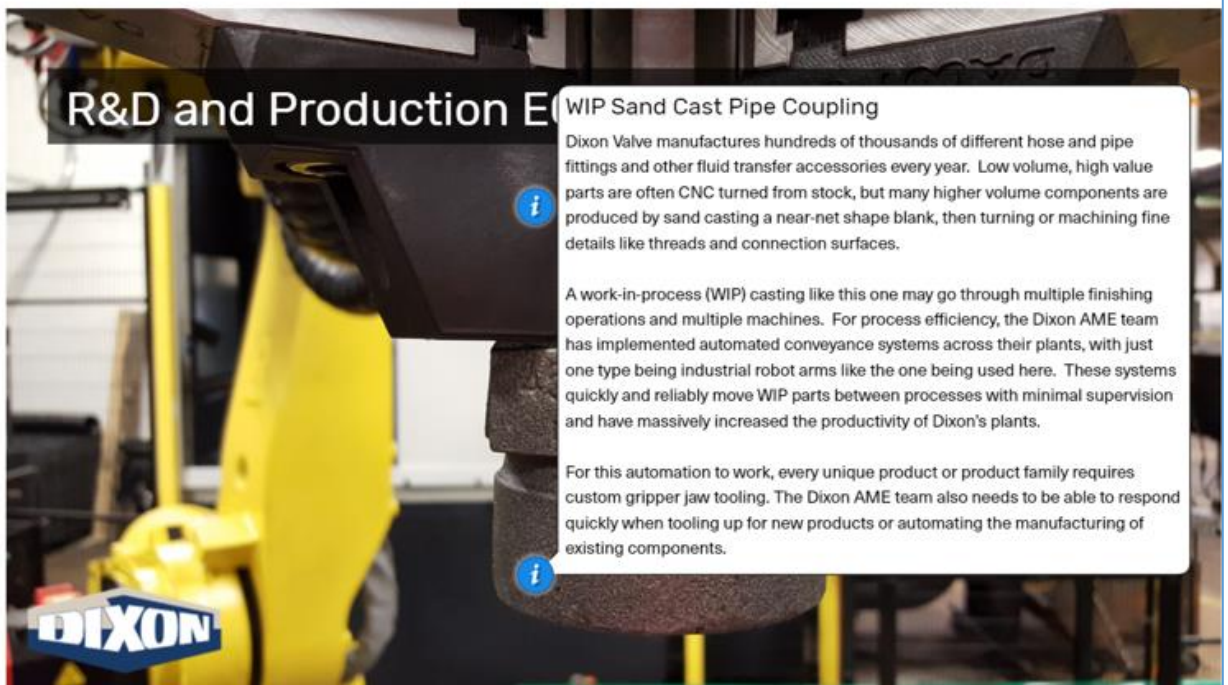
## R&D and Production EOAT for Process Automation

**Concentric Gripper Jaw**

Many Dixon products are cylindrical, so the most common method of gripping WIP parts in automation systems is with three-jaw concentric gripping systems. The gripper base itself is a standard off-the-shelf component, but each set of three jaws will be custom to the product being gripped. When a manufacturing line is changed over to produce a different product, an operator unbolts all product-specific tooling and swaps it with the new product's tooling.

The AME team's prior jaw development workflow was to design a jaw and send it to their machine shop to cut a set out of steel, which often took two weeks. If modifications or re-design were necessary, each iteration was usually another two weeks at a cost of about US\$1000 per set. The result was a workflow that wasn't agile and meant that even routine automation improvements and updates would often take months to implement. Although cost wasn't the primary driver, frequent iterations did also tend to add up over time as well. Dixon's AME team wanted to move faster and solve more problems for the company.

- Agile = Behendig
- Tend = neigen tot



## R&D and Production EOAT for Process Automation

**WIP Sand Cast Pipe Coupling**

Dixon Valve manufactures hundreds of thousands of different hose and pipe fittings and other fluid transfer accessories every year. Low volume, high value parts are often CNC turned from stock, but many higher volume components are produced by sand casting a near-net shape blank, then turning or machining fine details like threads and connection surfaces.

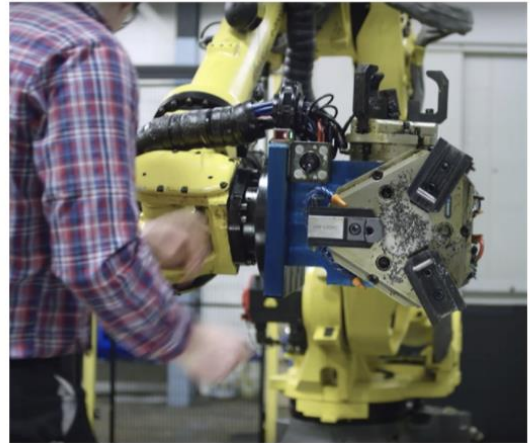
A work-in-process (WIP) casting like this one may go through multiple finishing operations and multiple machines. For process efficiency, the Dixon AME team has implemented automated conveyance systems across their plants, with just one type being industrial robot arms like the one being used here. These systems quickly and reliably move WIP parts between processes with minimal supervision and have massively increased the productivity of Dixon's plants.

For this automation to work, every unique product or product family requires custom gripper jaw tooling. The Dixon AME team also needs to be able to respond quickly when tooling up for new products or automating the manufacturing of existing components.



## Business Case Evaluation: Current Economics

- Two week design iteration
- ~100 sets of three jaws/year, with 30-50 unique designs
- Blocks automation implementation
- ~US\$100k/year tooling spend on these specific jaws



- **Business Case Evaluation**
  - Kostenreductie en levertijd van bijvoorbeeld 2 weken naar 24h.

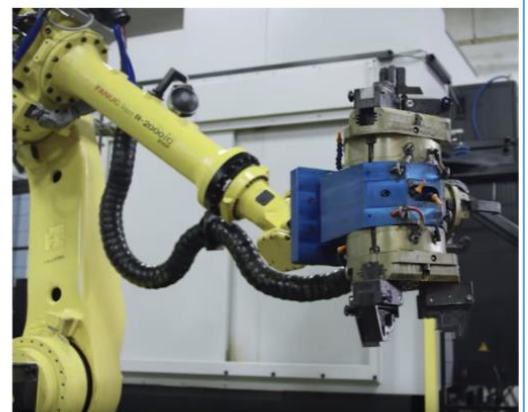
## Critical Functional Requirements

Precisely locate on complex part geometries

Grip up to 4.5 kg (10 lb) payload through rapid accelerations

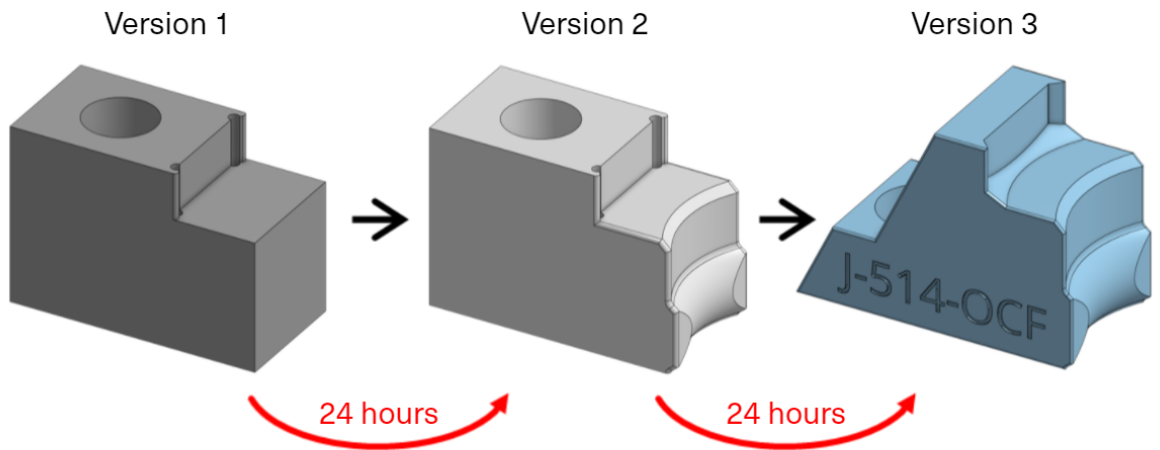
Rapidly turn around new tooling designs

Withstand wear and impact over jaw lifetime



- **Core Functional Requirements**

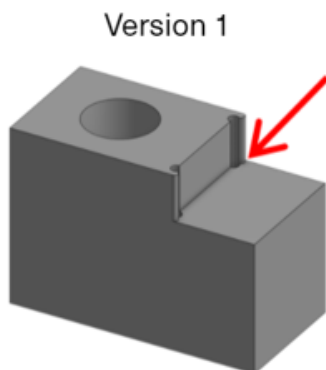
## Design, Testing and Redesign



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- **Redesign and testing**
  - Each iteration is only one day.

## Design, Testing and Redesign



### Original CAD Design

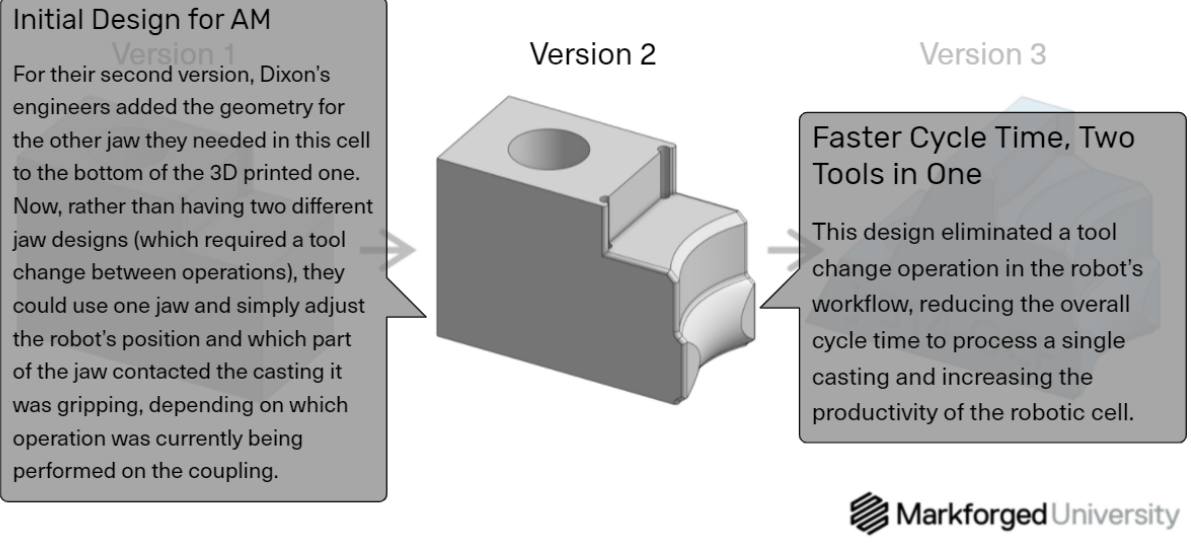
For the first version of the jaw, the original 3D model that was designed for CNC machining was simply 3D printed as-is to prove out the process. There were a few features that were unnecessary for a 3D printed version, that were holdovers from the original design, which was intended to be machined.

You can't machine sharp internal corners because endmills can only cut down to their own radius, so the design included corner relief holes that would normally be drilled (see red arrow). A 3D printer is completely capable of printing a sharp corner so the hole features were no longer necessary.

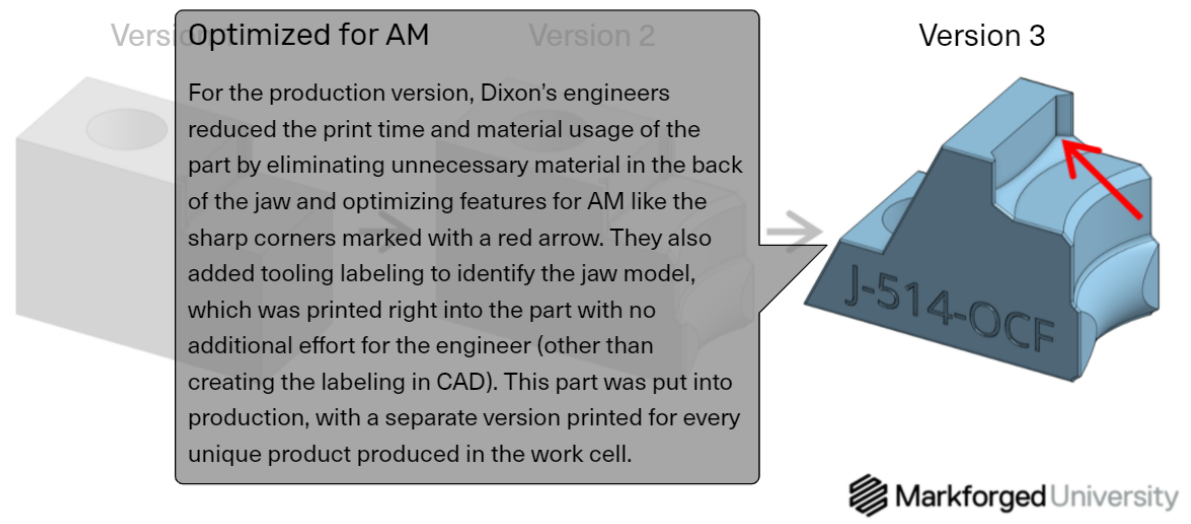
This jaw performed just fine but their robotic automation cell needed a second set of jaws for another operation on the other side of the part with a different geometry, and they wanted to improve the robot's workflow further.

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## Design, Testing and Redesign

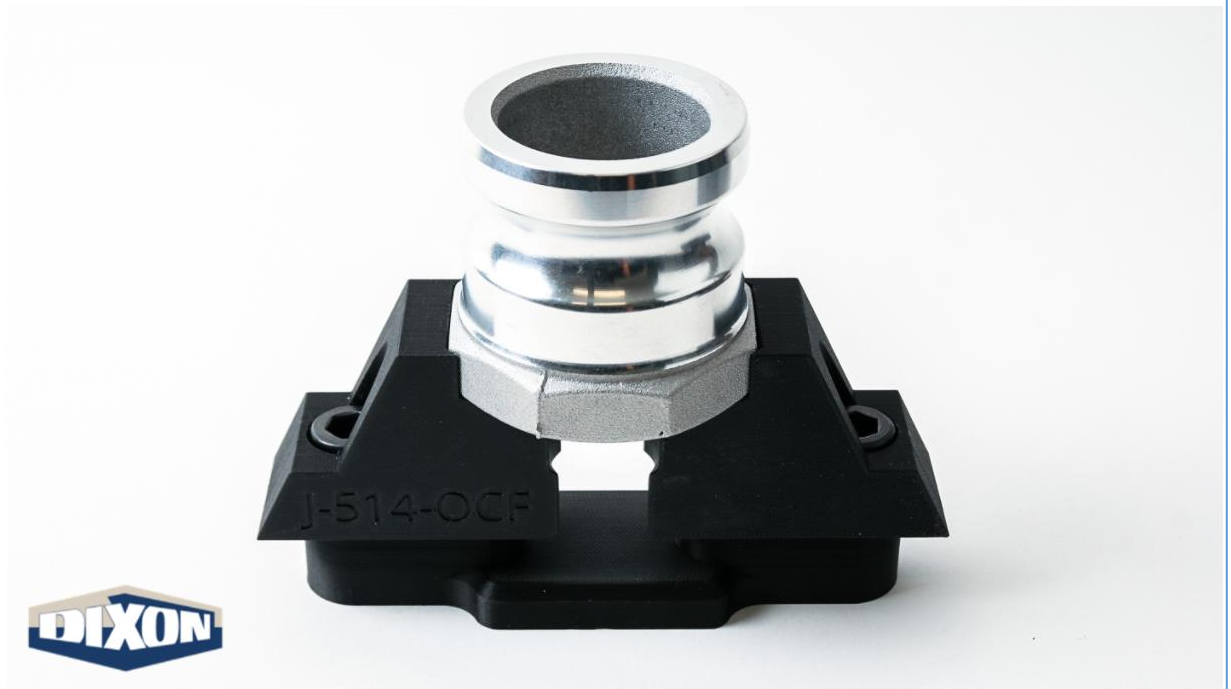


## Design, Testing and Redesign





- **Finished grippers**



## ROI Metrics

### Immediate Business Outcomes (per 3 jaw set):

	Traditional	Markforged	Change
Cost	\$1000	\$81	-92%
Lead Time	2 weeks	30 hours	-91%

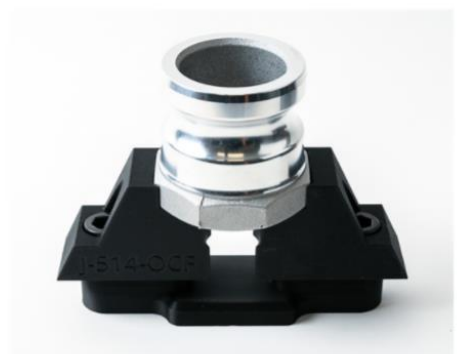


- ROI Metrics
  - Return On Investment.

## ROI Metrics

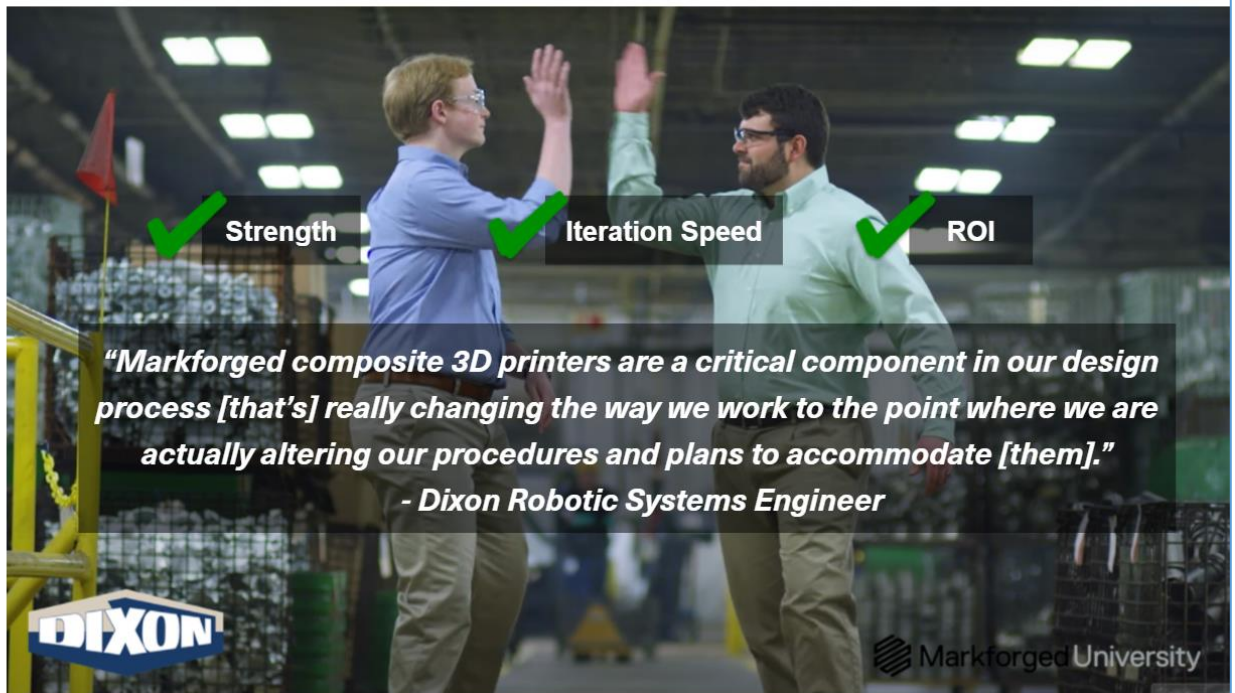
### Organizational Business Outcomes:

- + Process improvements with high value implemented weeks or months faster
- + Engineers give projects more intense focus with less context-switching penalties
- + Building an agile, 'fail-fast' engineering culture that's responsive and tests ideas quickly



- Agile = Weerbaar.





- **Project Recap**

Accommodate = aanpassen

Altering = wijzigen



- **Module Review**

Put the five steps in the Markforged Design for AM Framework in the correct order

1. Identify the root problem to be solved
2. Estimate the business case of using 3D printing for the problem
3. Identify all of your critical functional requirements and design an MVP
4. Configure and print a part
5. Implement the printed part and test it, for feedback into your next design



Which is an example of an organizational-level business impact that Dixon Valve experienced as a result of integrating 3D printing into their engineering work?

- Fully identified functional requirements that are critical to a tool performing well
- A force applied across a small area of a fixture as a part dropped into it
- An engineering culture that encouraged fast prototyping and testing to get results quickly
- Large cost- and lead time-savings as a result of 3D printing their end-of-arm tooling

True/False: When estimating the business case of using 3D printing to solve the problem at hand, we should develop a comprehensive ROI for every problem we're investigating.

- True
- False

- Comprehensive = veelomvattend. Essentie van het verhaal is dat er geen uitgebreide ROI-onderzoek hoeft plaats te vinden. Hier wordt immers ook gesproken over “estimating” hetgeen schatten betekent.

## Results

Your Score: 100% (30 points)

Passing Score: 80% (24 points)

Result:



Congratulations, you passed.

Finish Module

Review Quiz

## C1.7 - Common Manufacturing Applications



- **Common Manufacturing Applications**

## Module Overview

Tooling and Workholding

Fixturing for Assembly and QC

Sensor and Safety Equipment Mounting

Workplace Organization and 5S Fixtures

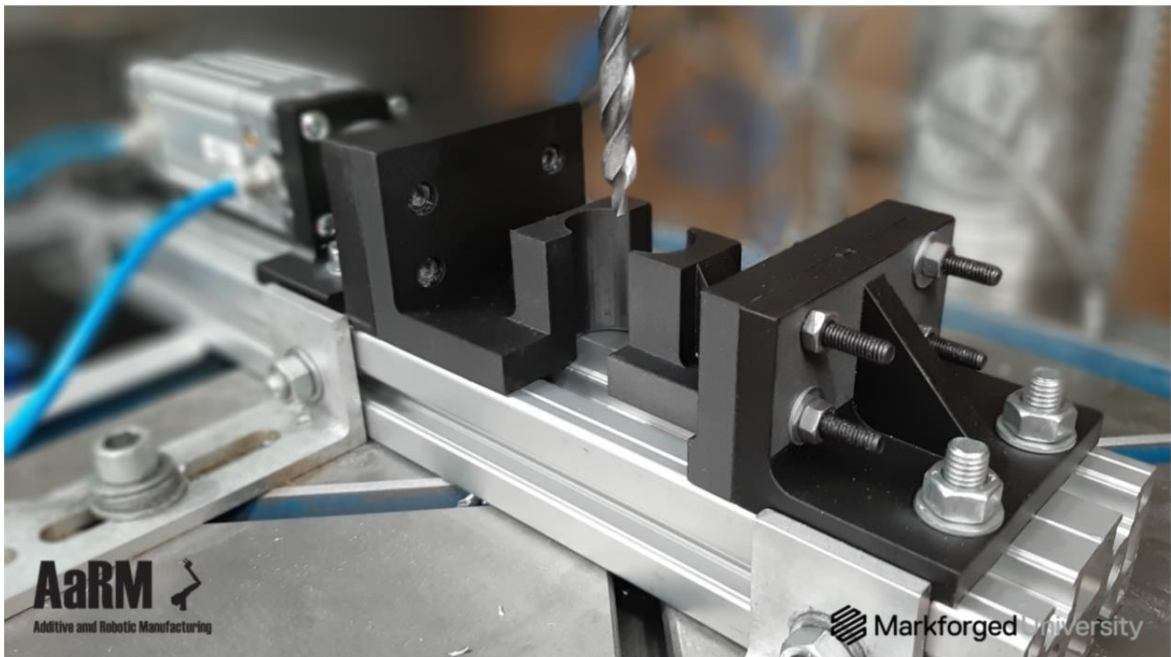
- **Module Overview**

## Part 1: Tooling & Workholding

- **Part 1: Tooling & Workholding**

## Softjaws and Clamping

- **Softjaws and Clamping**



- **AaRM Clamping Jaws**

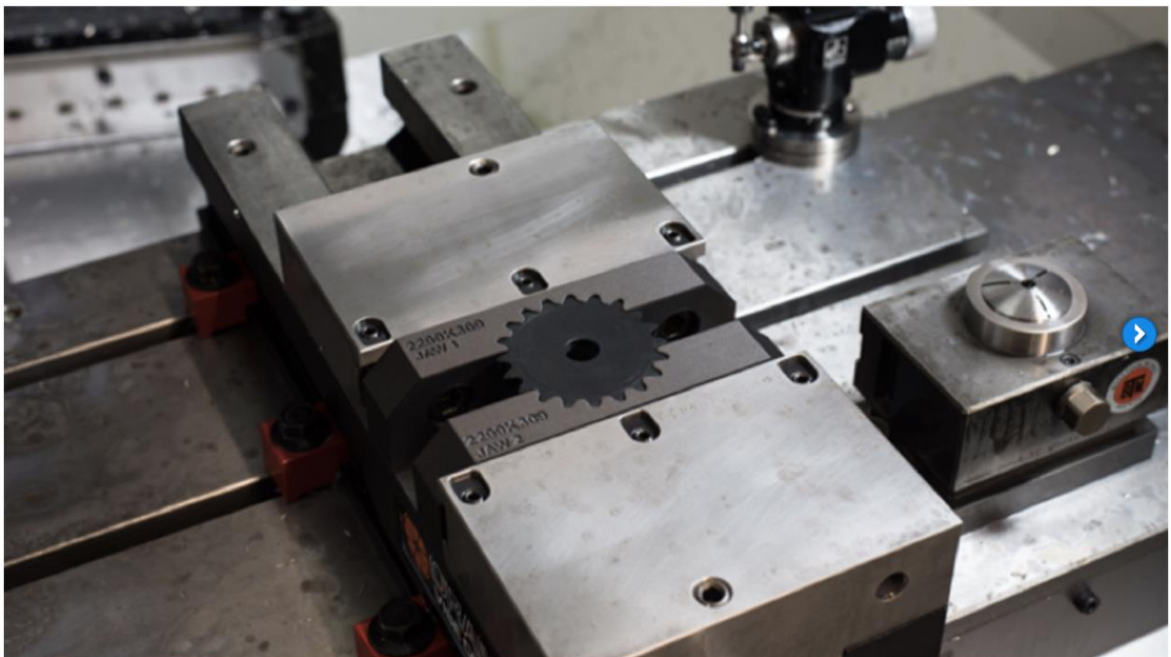
## What are Soft Jaws?



Custom, replaceable workholding  
“Soft” compared to standard steel jaws  
Represent a production inefficiency

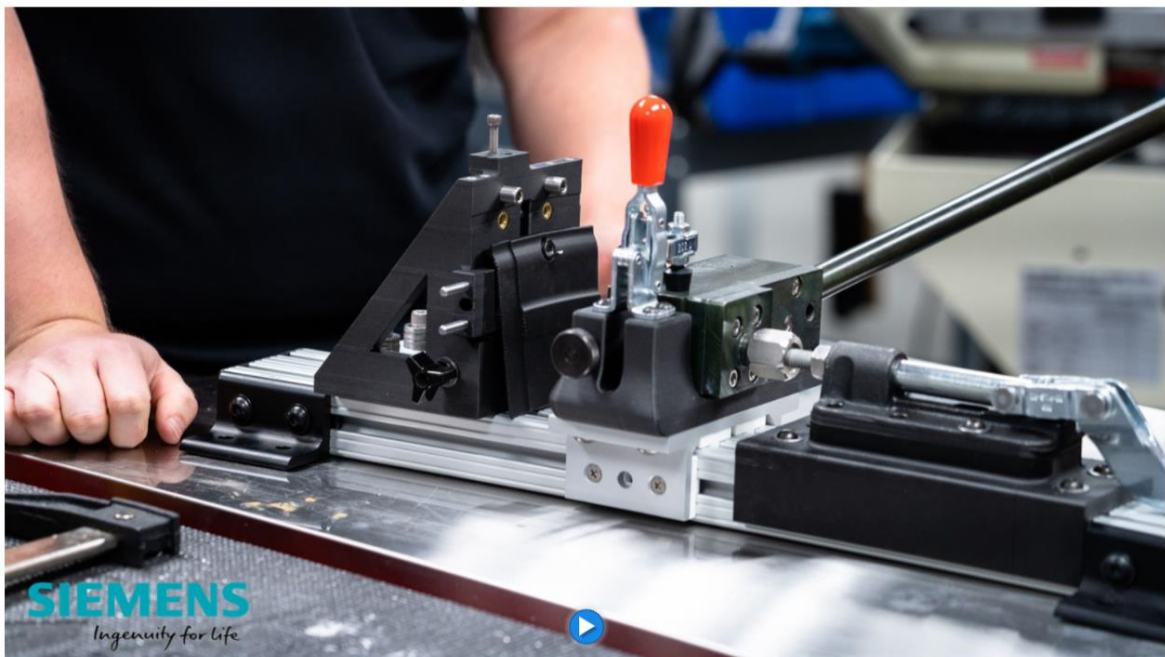
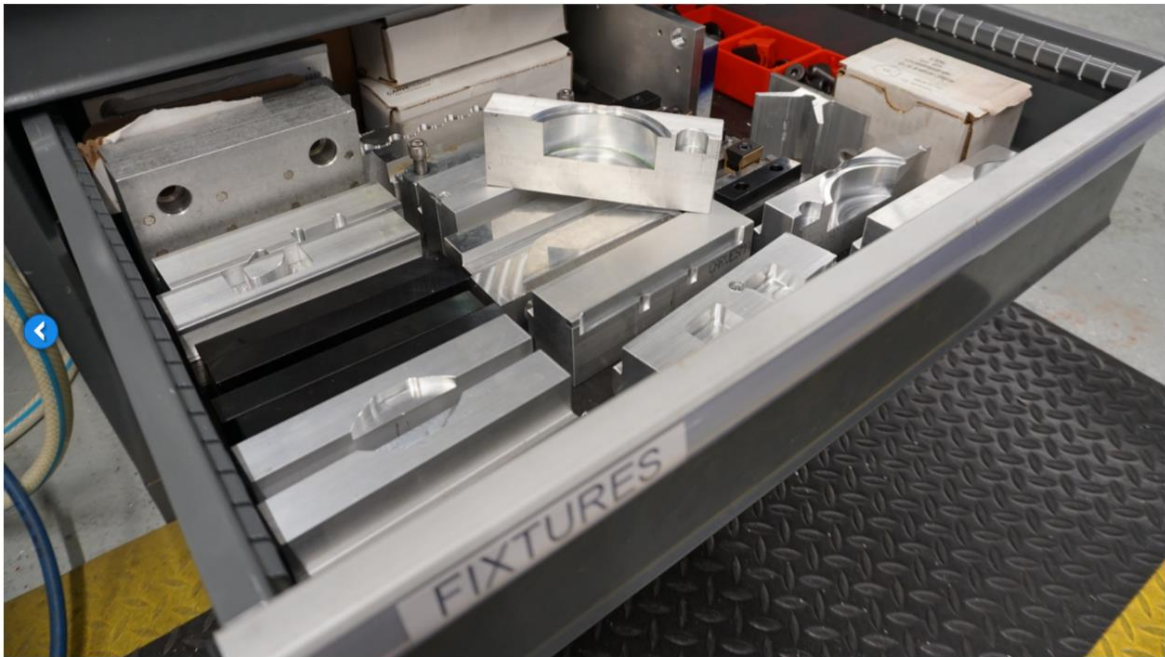
[Learn Why](#)

- **What are Soft Jaws?**

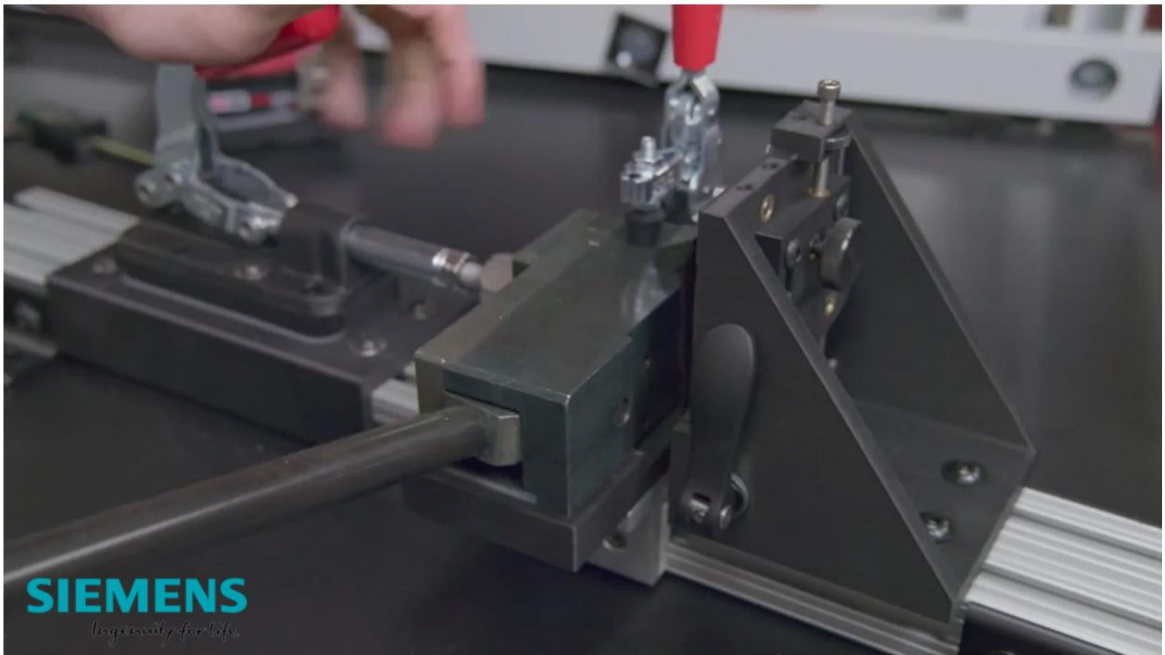
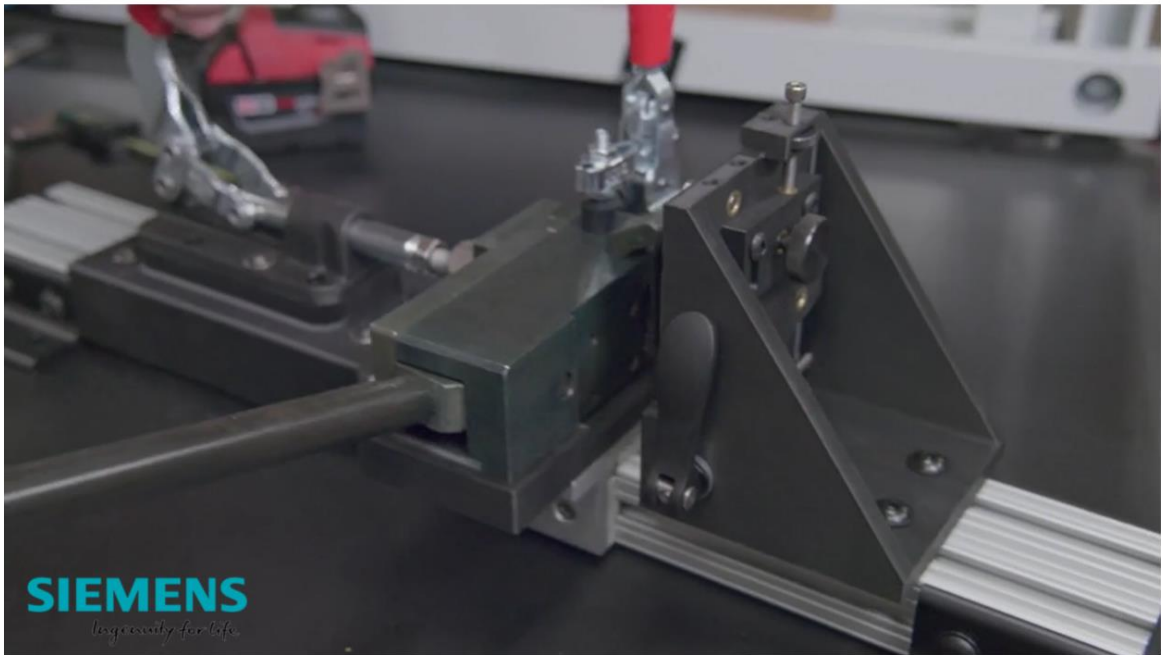


- **Where to Look for Softjaw Opportunity?**

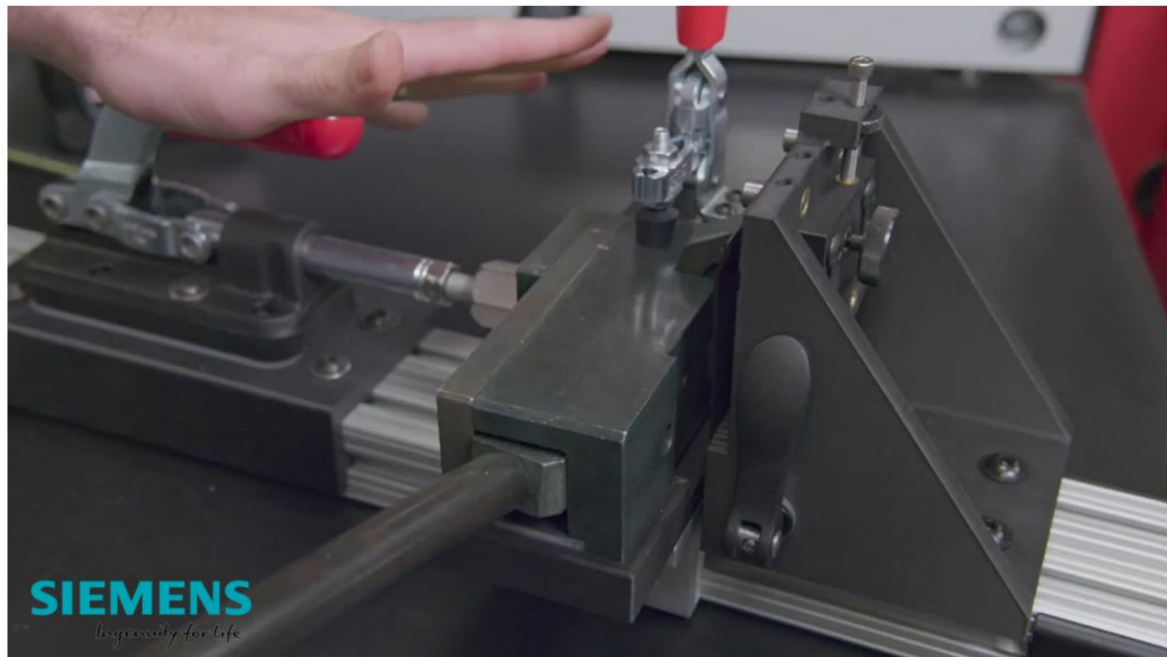
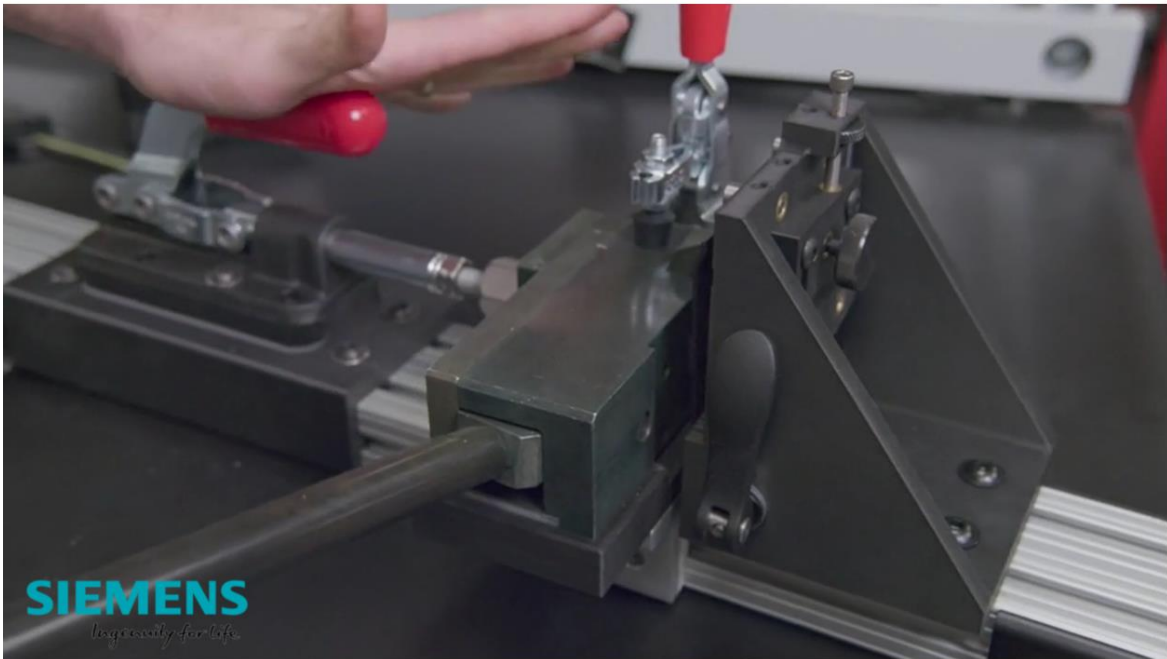


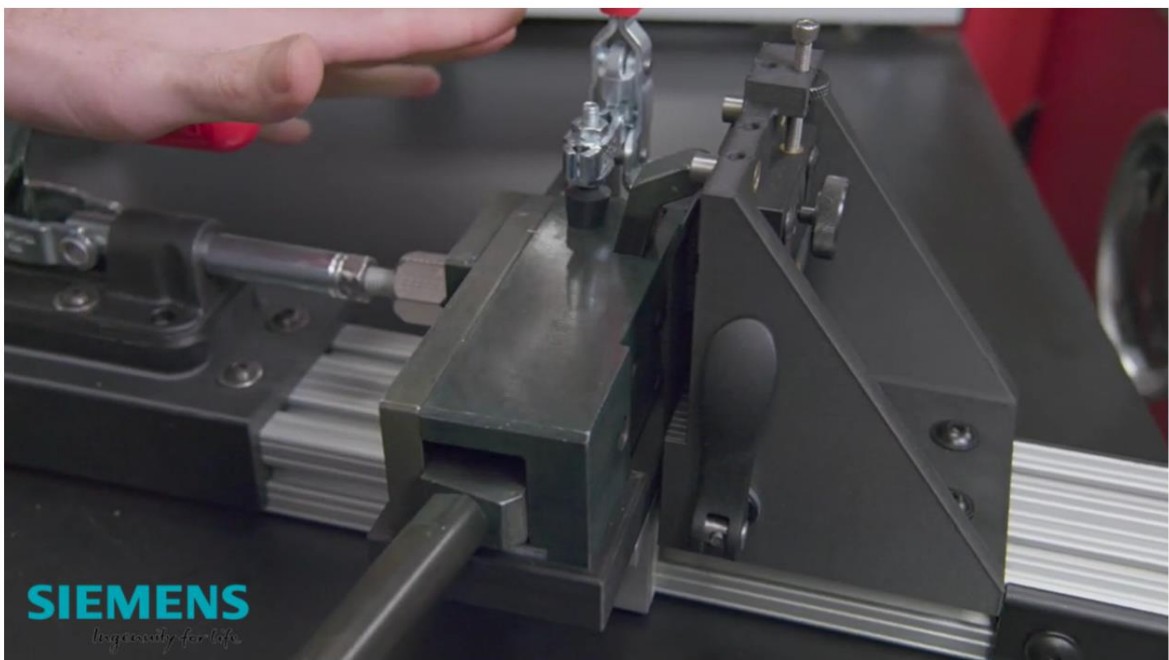
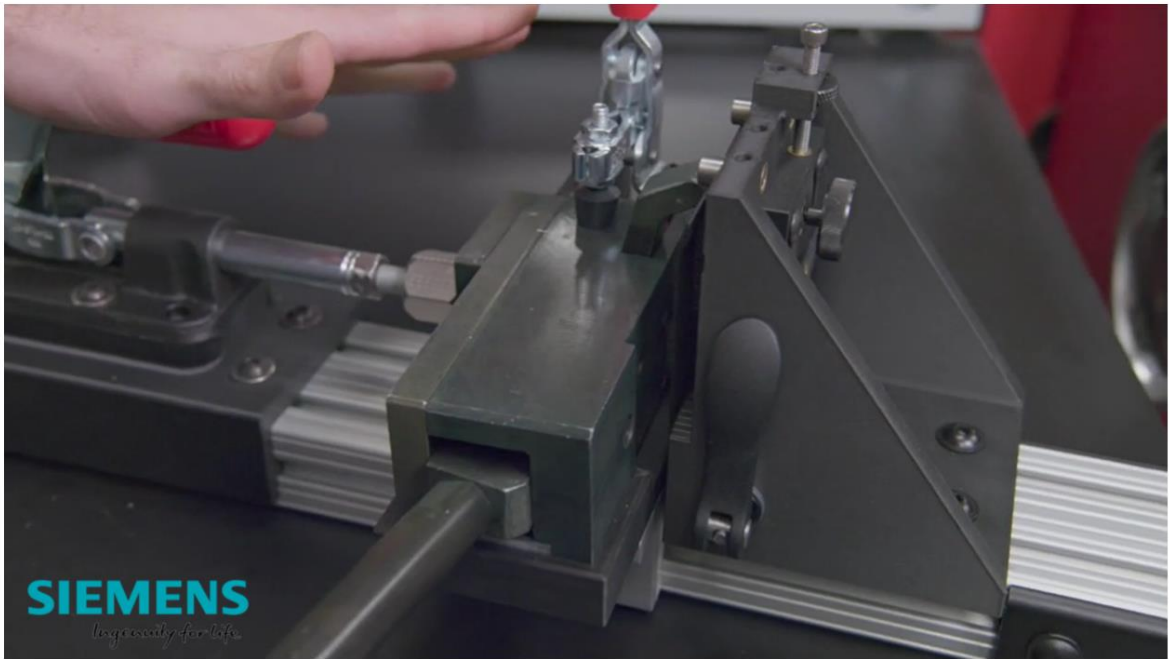


- **More Complex Clamp Tooling**
  - **Following images of clamping process**



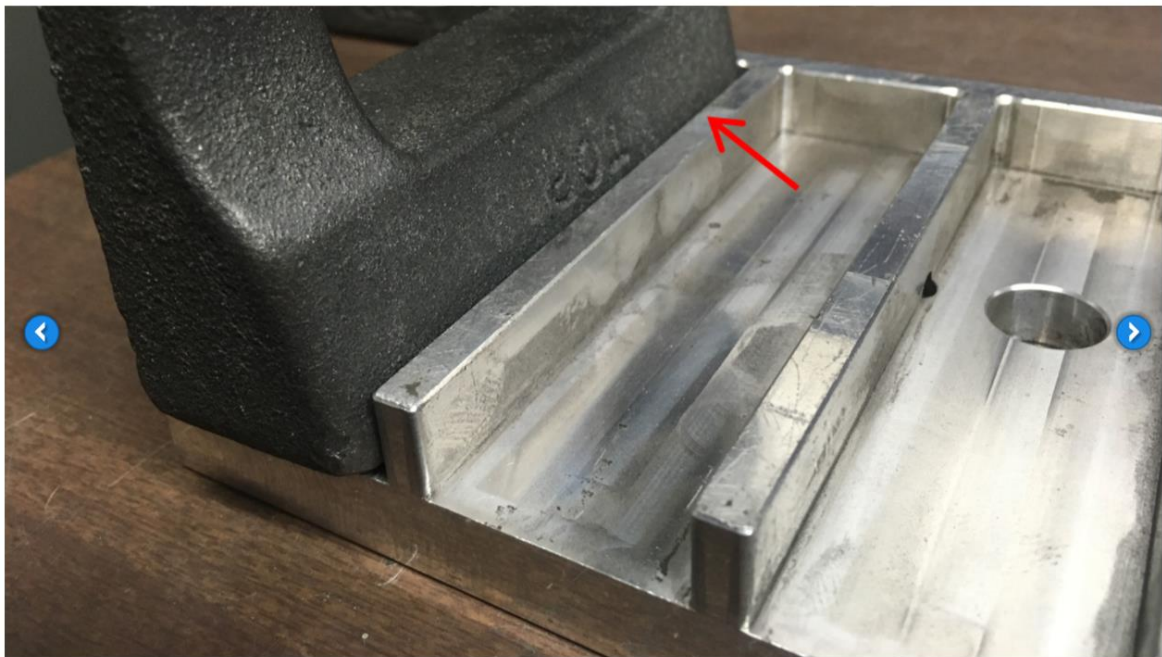








- **Robotic Grinding Fixture**



- Original made of aluminium causes wear and tear reduces the live time of the fixture.
- Interfering with the fixture (red arrow).

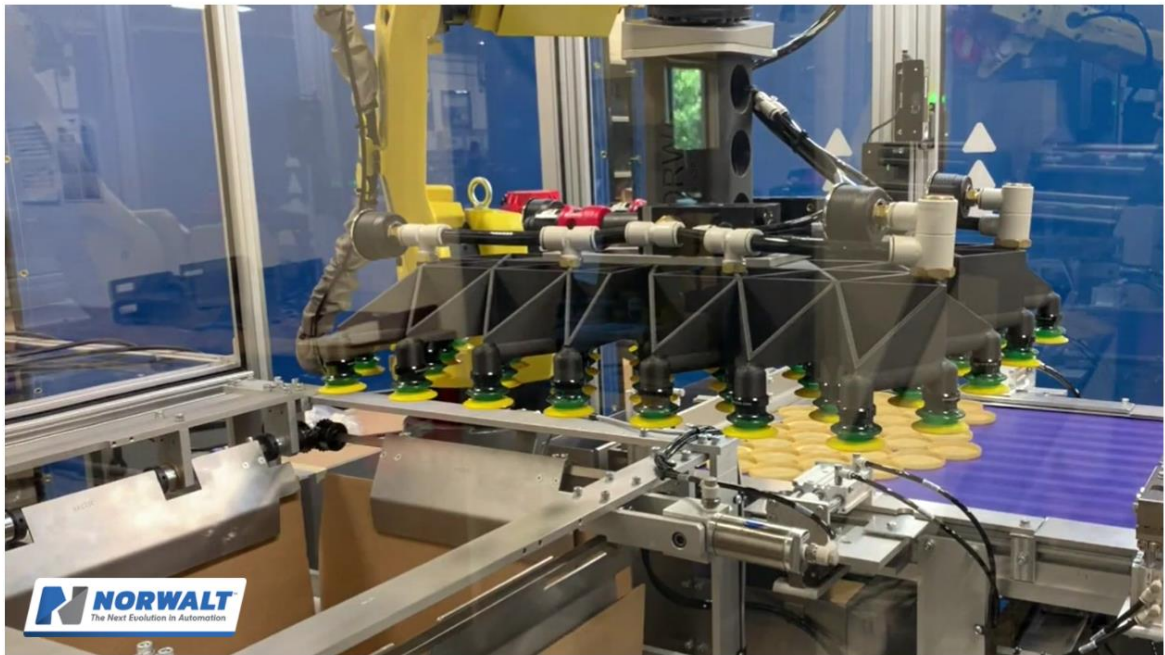




○

## End-of-arm Tooling (EOAT) for Industrial Robots

- End-of-arm Tooling (EOAT) for Industrial Robots



- **Vacuum Pick-and-Place: Norwalt Design**
  - Much lighter construction in stead of metal solutions.
  - Much more quickly accelarions and de-accelarations (massatraagheid? Mass Inertia?)
    - Gives much more productivity.



- **Unpowered Cobot Gripper: Siemens**

- Een cobot of co-robot (van collaborative robot, meewerkende robot) is een robot die bedoeld is om samen te werken met mensen in een gemeenschappelijke werkomgeving. Een cobot verschilt daarmee van andere robots, die ontworpen zijn om zelfstandig of met beperkte begeleiding te opereren, zoals de meeste industriële robots tot 2010. Verder zijn cobots lichter, makkelijker verplaatsbaar en vaak goedkoper dan een grotere standaard industriële robot.



- **Vacuum EOAT – Packaging Automation**





# Custom Tooling

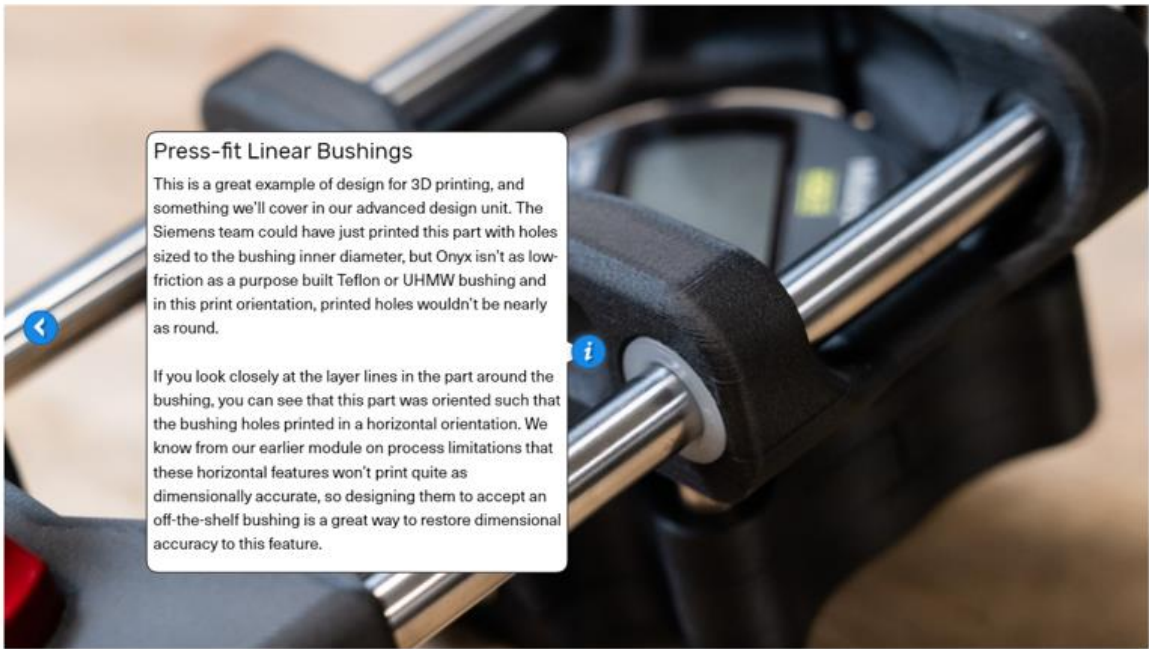


- **Custom Tooling**



- **Inspection Tool Siemens**

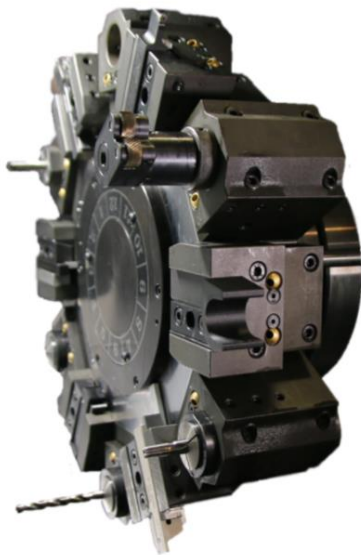




**Press-fit Linear Bushings**

This is a great example of design for 3D printing, and something we'll cover in our advanced design unit. The Siemens team could have just printed this part with holes sized to the bushing inner diameter, but Oryx isn't as low-friction as a purpose built Teflon or UHMW bushing and in this print orientation, printed holes wouldn't be nearly as round.

If you look closely at the layer lines in the part around the bushing, you can see that this part was oriented such that the bushing holes printed in a horizontal orientation. We know from our earlier module on process limitations that these horizontal features won't print quite as dimensionally accurate, so designing them to accept an off-the-shelf bushing is a great way to restore dimensional accuracy to this feature.



## CNC Lathe Bar Puller

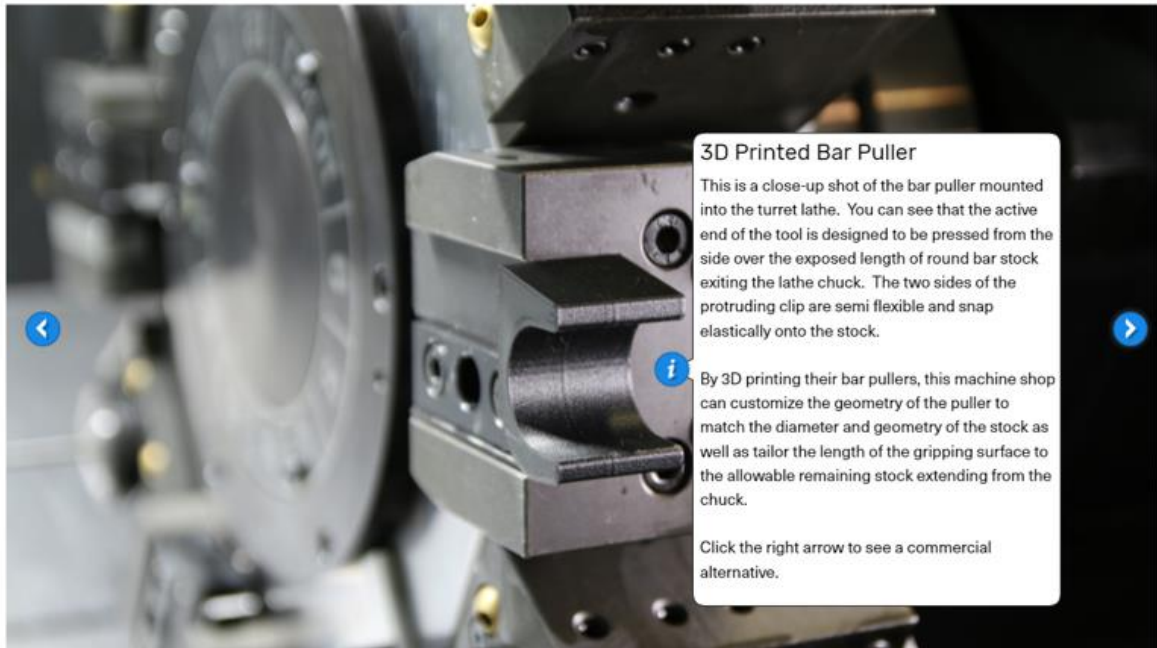
Automates production in lathes without bar feeder



Inexpensively expand existing machine capabilities



- **CNC Lathe Bar Puller**



- Dit is een close-up van de staftrekker die in de revolverdraaibank is gemonteerd. U kunt zien dat het actieve uiteinde van het gereedschap is ontworpen om vanaf de zijkant te worden gedrukt over de blootgestelde lengte van het ronde staafmateriaal dat de klauwplaat verlaat. De sleepzijden van de uitstekende clip zijn semi-flexibel en klikken elastisch op de kolf. Door hun staftrekkers in 3D te printen, kan deze machinewerkplaats de geometrie van de trekker aanpassen aan de diameter en geometrie van de kolf en de lengte van het grijppoppervlak aanpassen aan de toegestane resterende voorraad die uit de spankop steekt.

## Commercially Available Bar Puller

US\$700 - \$1000 standard CNC bar puller tool

Limited adjustable range of geometries

Collisions often damage both tool and lathe



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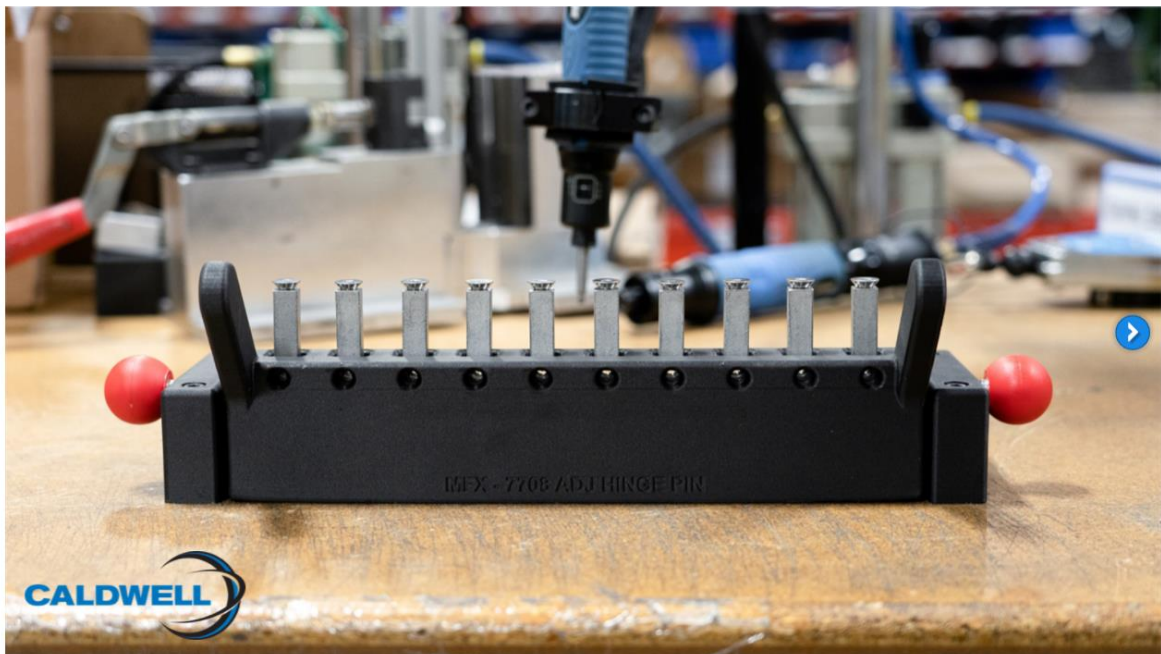
- Printed with Onyx with fiber glass reinforcement.
- Lower risk of damaging other parts of lathe by collision. The plastic gripper will break earlier.
- Much quicker redesigning of the model (available next morning).



- **Part 2: Fixtures**

## Assembly and Quality Control Fixtures

- **Assembly and Quality Control Fixtures**
  - Fixtures holds parts in position.



- **Assembly Fixtures – Caldwell Mfg.**

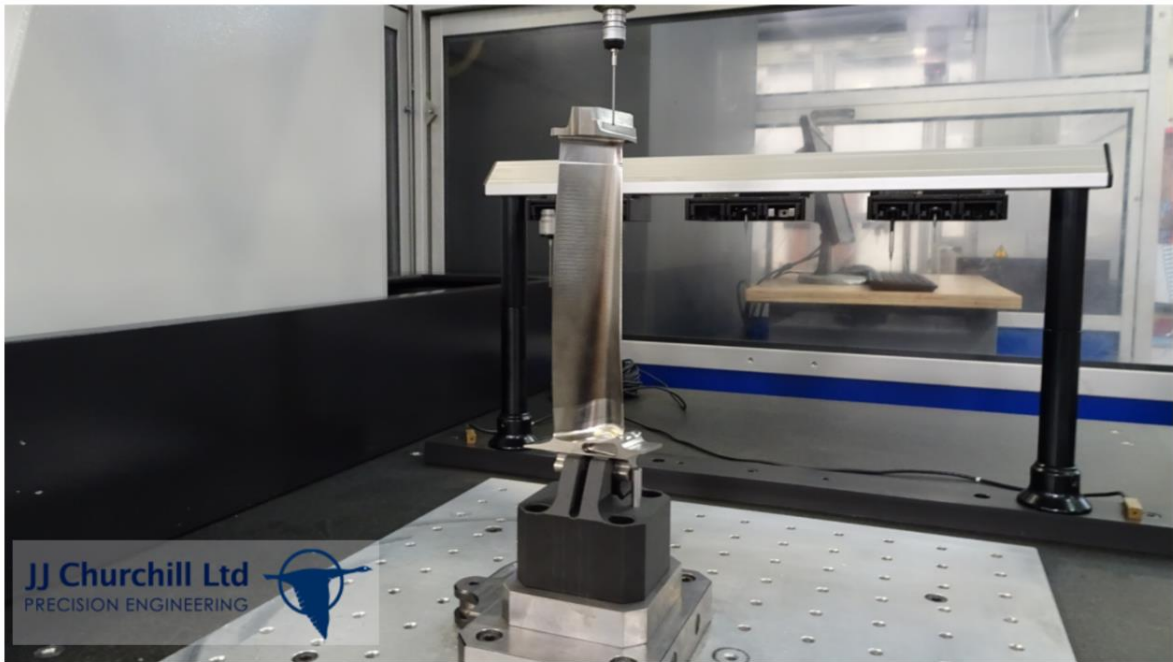




- Fixture for hinges, by using the cadmodel of the hinges.



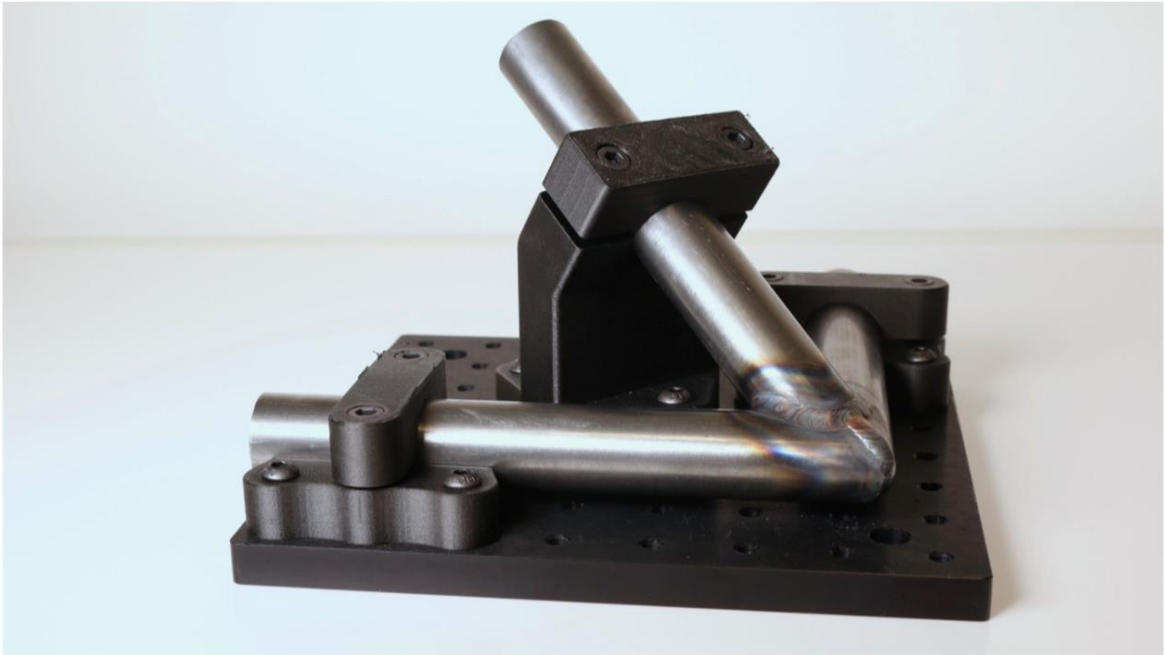
- Closer look of the fixture.



- **CMM fixturing – JJ Churchill Ltd**
  - CMM = Coordinate Measuring Machine

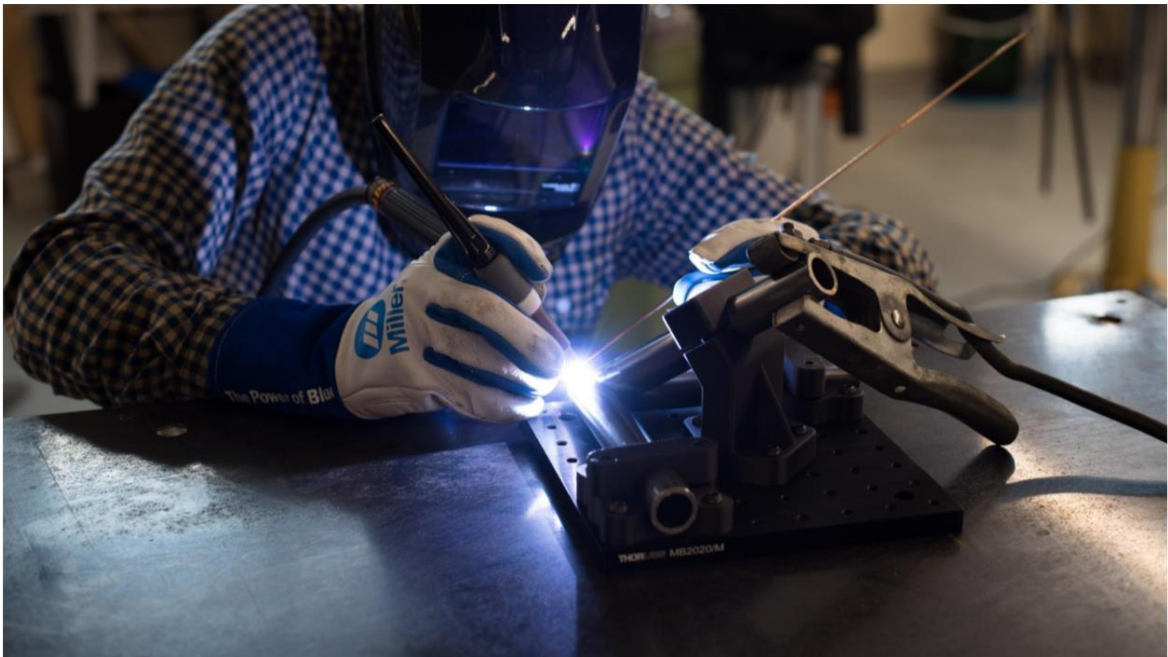
## Welding Fixtures

- **Welding Fixtures**
  - Despite the fact that the fixture needs to be far from the heat source, there are many applications for welding fixtures.



- **TIG Welding Fixture**

- Rudimentary design: not a quick clamp and release mechanism and not for high volume use. But it illustrates the concept.
- Well away from the heat zone.
- Gives plenty of clearance for the welder to access the joint.
- Closer to the heat section requires inserts







- **Laser Welding Fixture**

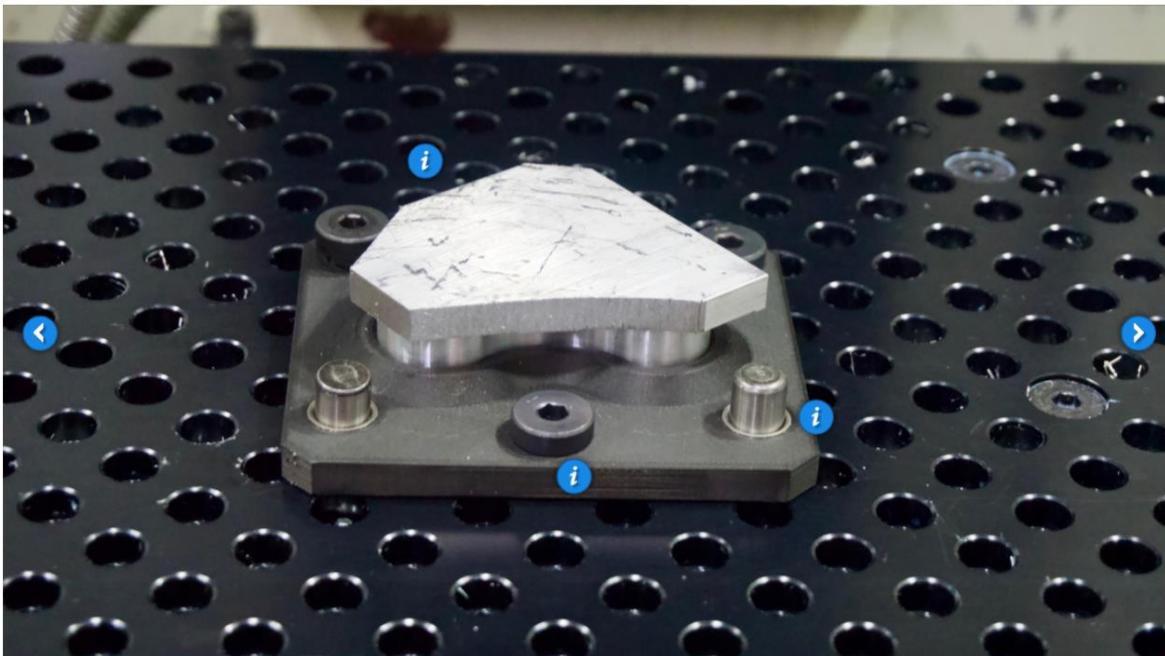
## Machining Fixtures

- **Machining Fixtures**



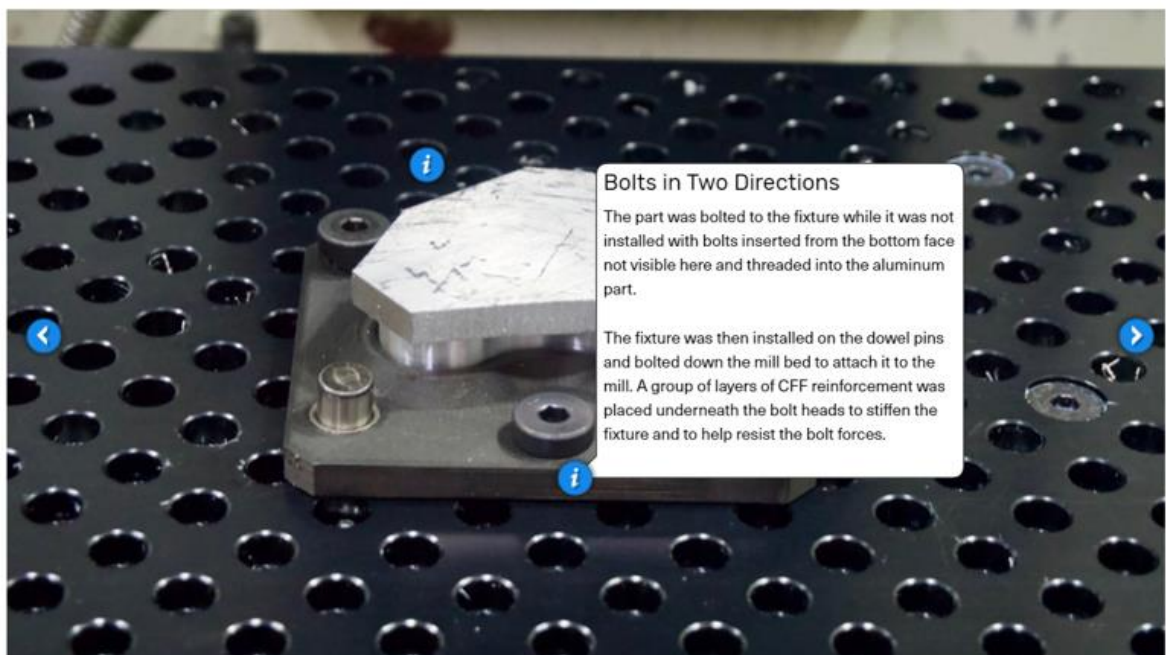
- **Motor Mount Machining Fixture**

- For an old bike rebuilding.
- Because of curve and other feature was not simple to hold during machining.
- So they print a machining fixture of it.

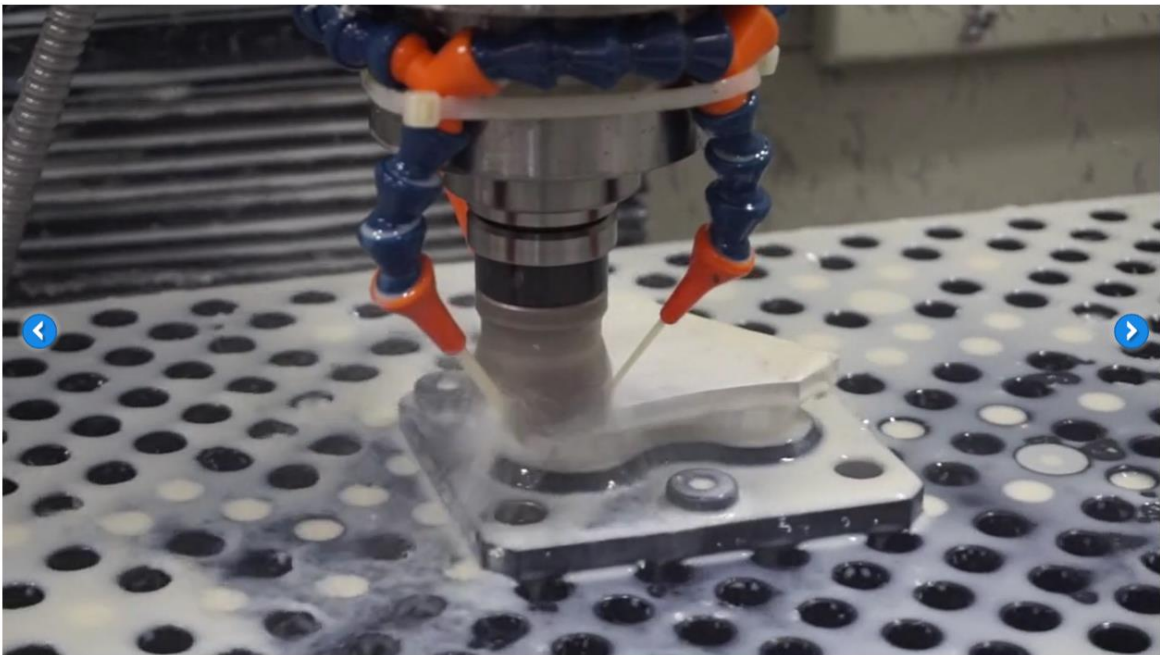
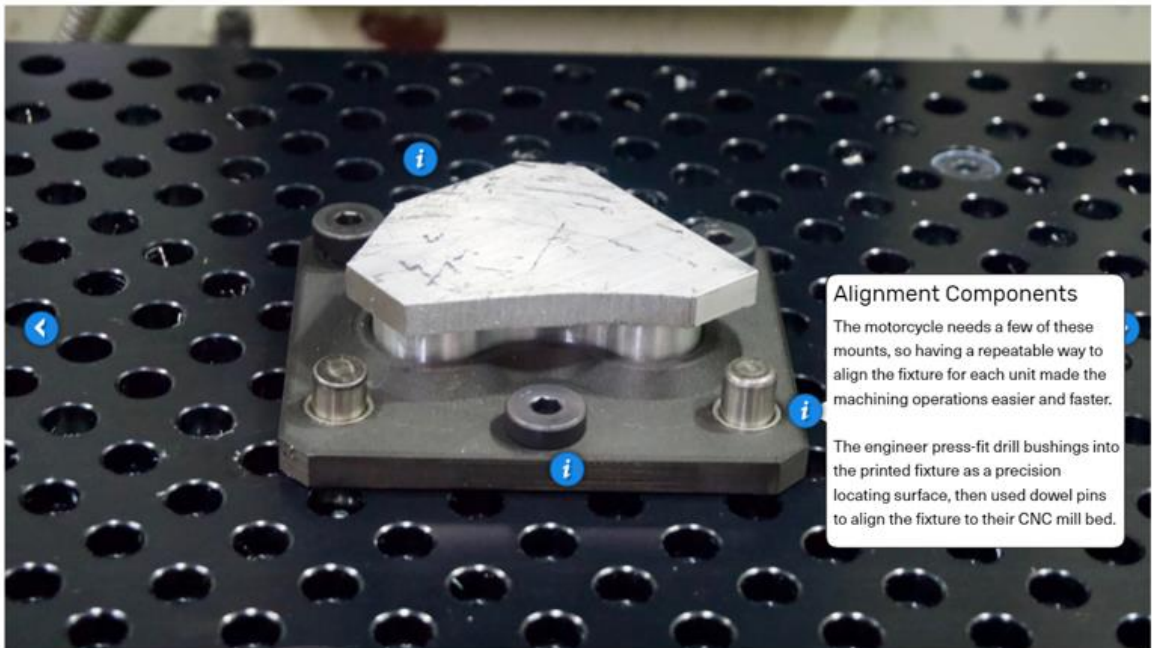




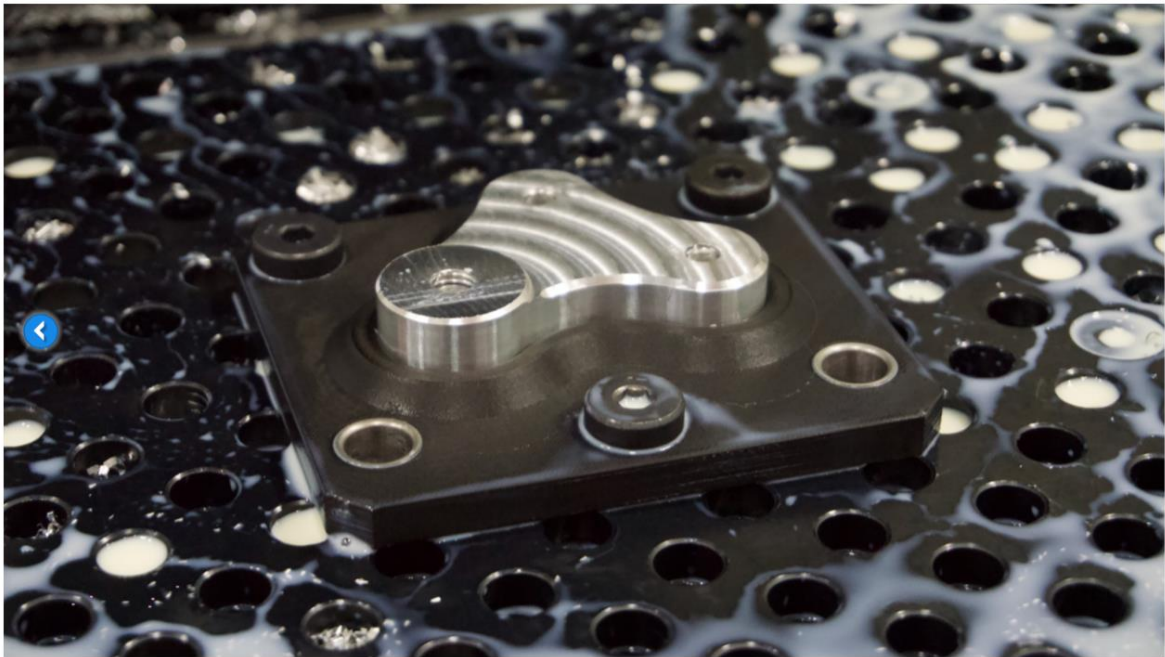
- Vise = Bankschroef





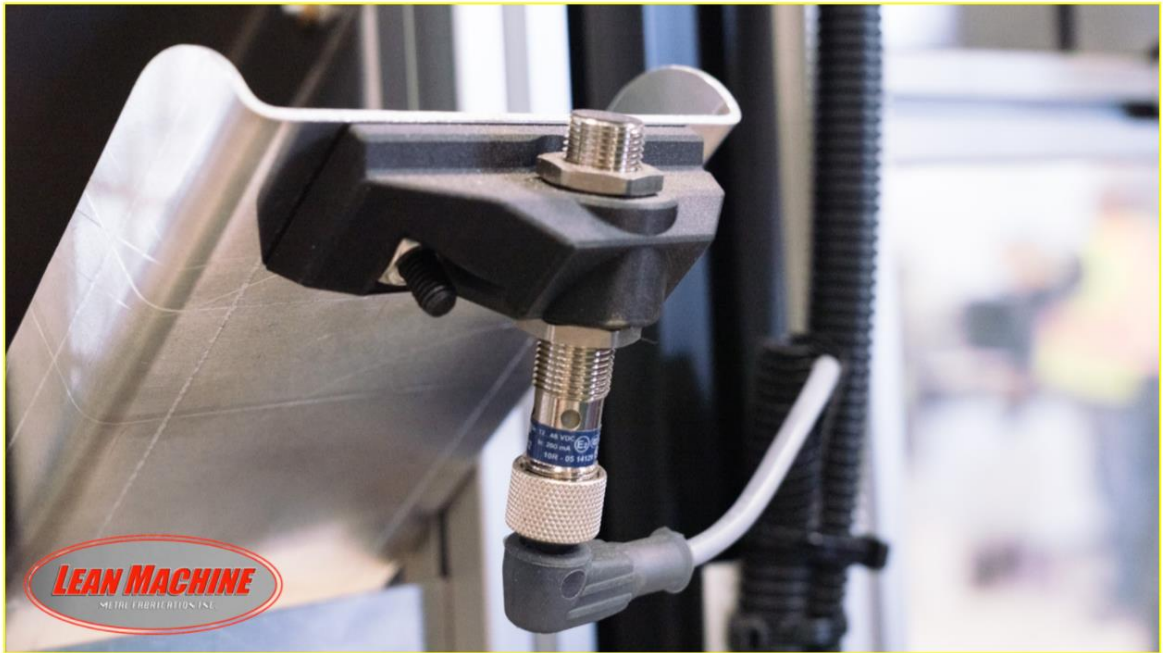


- Nylon will absorb moisture in these conditions, but composite fiber will not.

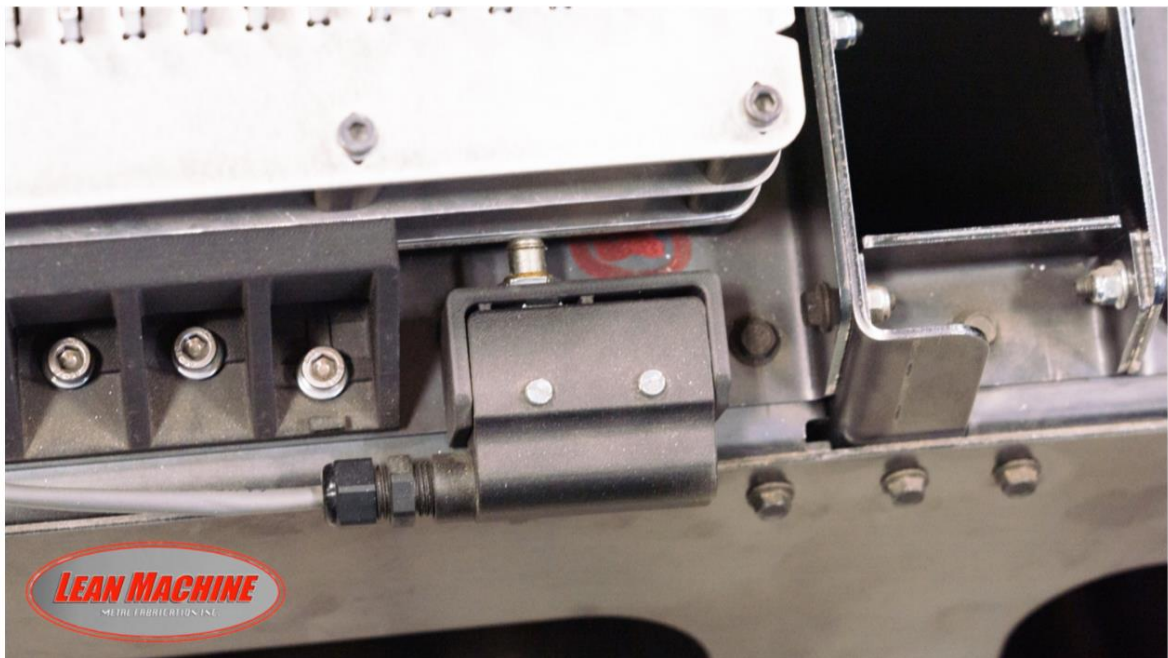


## Part 3: Sensor and Safety Equipment Mounting

- **Part 3: Sensor and Safety Equipment Mounting**

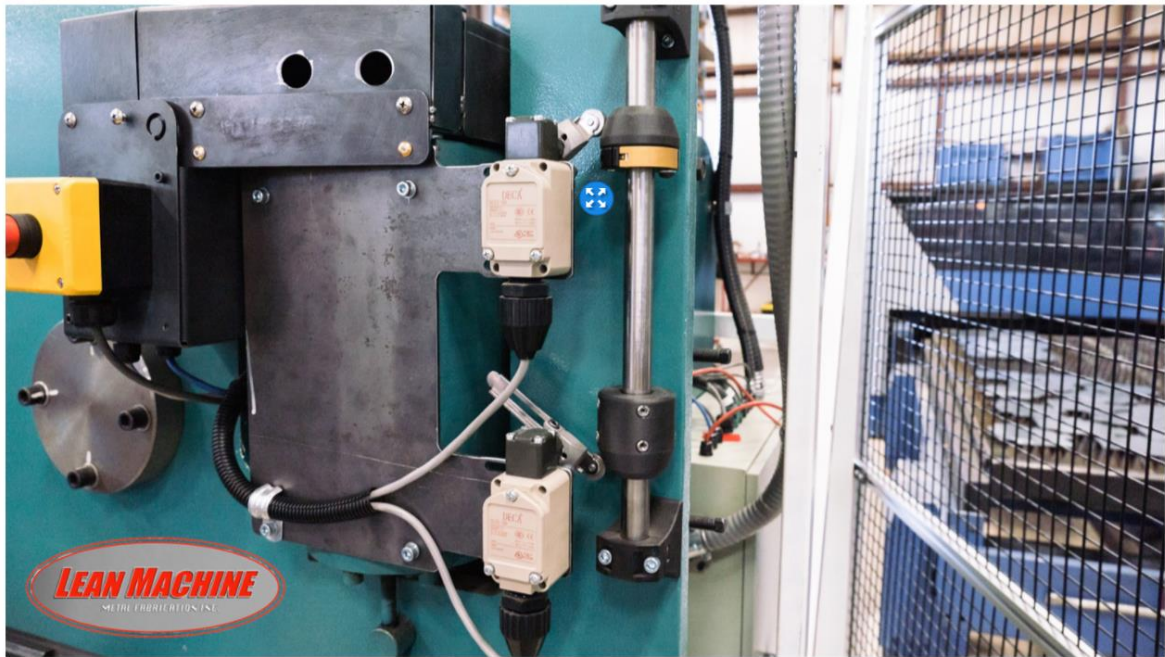


- **Proximity Sensor Bracket**
  - Proximity = nabijheid.



- **Contact Sensor**





- **Updating Aging Equipment**

- Backside of a sheet metal press in an automatic workcell: Upper and lower extent for quickly adjustment travel distance changing between different press operations.





## Part 4: Workplace Organization and 5S Systems

- **Part 4: Workplace Organization and 5S Systems**

### What is 5S?

Workplace organization methodology

Origins in Japan, adopted by Toyota

Minimizes downtime and inefficiency  
due to confusion



1. Scheiden
2. Schikken
3. Schoonmaken
4. Standaardiseren

## 5. Standhouden of systematiseren

☰ C1.7 - Common Manufacturing Applications

RESOURCES



☰ C1.7 - Common Manufacturing Applications

RESOURCES



- 5S Tool Organizers





- **Outdated 5S Tool Organizers**
  - Foam solutions will be damaged after wear and tear by aging of time.



## Change is the Downfall of 5S

Custom foam inserts for 5S organizers are great...until tools and needs change

Foam isn't modular, most facilities don't have tools to properly modify

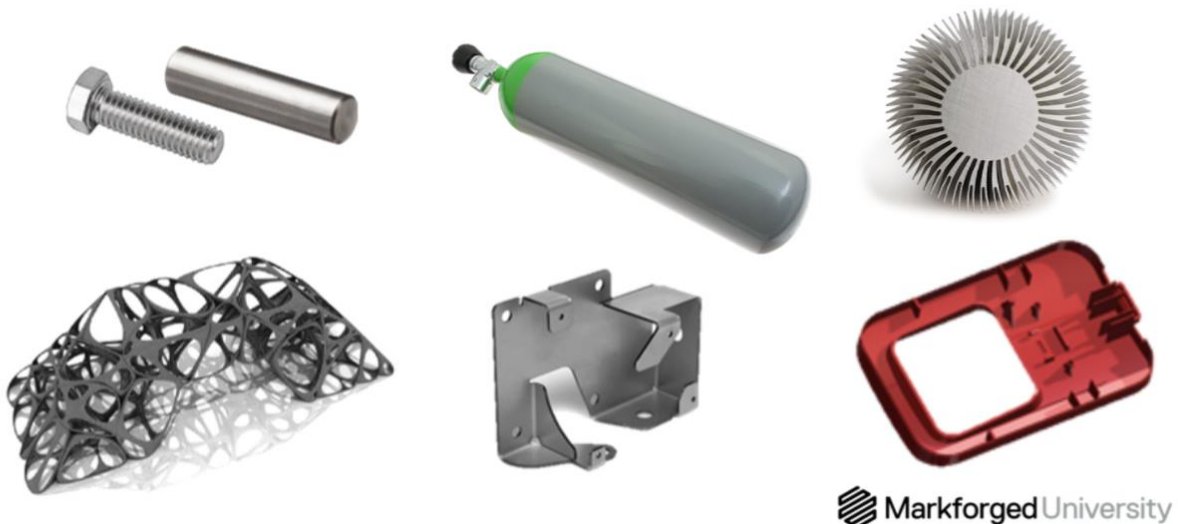
Modular 3D printed 5S organizers enable future-proof continuous improvements



- **3D Printed Tool Holder**

- When they update their calipers (new model) and the shape of the holder is not appropriate tot he new tool, only the single holder needs an update, not the intire shadowboard.

## What's NOT an ideal application?



- **What's NOT ani deal application?**



## What's NOT an ideal application?



### Commerical Off-the-Shelf (COTS) Components

COTS components are commodity parts like bolts, nuts and dowel pins. They have specialized functionality and as commodities, their high-volume manufacturing processes have been highly optimized to produce consistent functionality at the lowest possible price. It typically doesn't make sense to print these components, because a 3D printed version won't be able to exactly replicate the functional performance (dowel pins are not anisotropic for example) and will be significantly more expensive than a COTS version that's been manufactured in high volume. Buy these components and save your 3D printing resources for more impactful projects.

- Commodity = Gemeengoed.

## What's NOT an ideal application?



### 3D Lattice Structures

Common marketing materials for 3D printing often demonstrate lacy lattice organic structures, sometimes known as Voronoi tessellations. These structures are a poor fit for extrusion-based FFF-style 3D printing and should be avoided in functional parts.

FFF printing is designed for printing continuous paths, not individual points or extremely small sections and these lattice structures generate tons of these tiny features on every layer. If you need weight reduction or low part density, design a solid geometry instead and use Eiger to reduce weight by adjusting the part's infill type and density.



## What's NOT an ideal application?

### High-Pressure Vessels

3D printed parts SHOULD NOT be used to create static pressure vessels, especially for holding gaseous pressure that stores significant potential energy. Pressurized liquids and gases apply forces normal to the surface of their containers, and with 3D printing this means that the pressure will always be producing expansion forces in the Z-axis direction of the part that can cause failures between layers. The printed layer lines also serve as stress concentrators that aid in sudden crack initiation between layers. Should a crack develop, the pressure will cause it to propagate and the part will break, releasing the pressure and stored energy in an instant and often creating shrapnel from the part. 3D printed pressure vessels are extremely dangerous and should not be created.



## What's NOT an ideal application?

### Extremely Fine Features (<0.5 mm [0.02 in])

Parts with microscopic or intricate features below this level tend to be a poor fit for extrusion 3D printing. Markforged composite printers print plastic in 0.4 mm [0.016 in] wide paths with layer heights ranging from 0.05-0.25 mm [0.002-0.01 in] which makes it difficult to accurately reproduce these fine features. Consider producing just the section of a part with these fine features with another process, like machining or wire EDM, then joining that with a larger 3D printed section to form an assembly.

If you do have to 3D print fine features, you'll get the highest resolution in the Z-axis, so features like tooling labeling will print with the highest fidelity if you place them on the vertical walls of a part versus the horizontal faces.

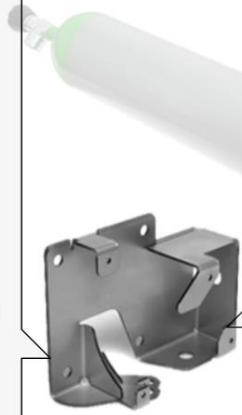


## What's NOT an ideal application?

### 1:1 Sheet Metal Geometries

In the section on sensor mount applications we discussed how a 3D printed part can replace a sheet metal part functionally, but will require a different design to account for the 3D printing process.

3D printing parts that were originally designed as sheet metal pieces, without redesigning them, is a bad idea and should be avoided.



Sheet metal retains its strength tangent to the sheet surface as it's bent, producing thin, yet strong geometries with tabs in different planes.

3D printing is anisotropic and those thin tabs designed for sheet metal processes easily snap off when printed. Sheet metal geometries are also inherently mostly hollow and require substantial support material when printed. To re-design for 3D printing, it's best to make a more solid, blocky geometry that will print with infill.

## What's NOT an ideal application?

### High Aspect Ratio Parts

Aspect ratio is a metric we use to evaluate the geometry of an overall part for suitability for 3D printing. When we look at aspect ratio, we compare the parts largest dimension to it's areas of smallest dimensions. For this injection molded case here, we see that it has a fairly large footprint, but it very thin throughout that large area. Sheet metal and injection molded parts are very specific examples of this type of geometry but there are many more too.

Parts with high aspect ratios tend to be very thin, yet tall or wide and they have a higher risk of warping, falling over while printing or otherwise printing unsuccessfully. Re-designing these parts to have more solid or substantial geometries is usually a good idea.




Aspect ratio is a metric we use to evaluate the geometry of an overall part for suitability for 3D printing. When we look at aspect ratio, we compare the parts largest dimension to it's areas of smallest dimensions. For this injection molded case here, we see that it has fairly large footprint, but it very thin throughout that large area. Sheet metal and injection molded parts are very specific examples of this type of geometry but there are many more too. Parts with high aspect ratios tend to be very thin, yet tall or wide and they have a higher risk of warping, falling over while printing or


otherwise printing unsuccessfully. Re-designing these parts to have more solid or substantial geometries is usually a good idea.

Beeldverhouding is een maatstaf die we gebruiken om de geometrie van een algemeen onderdeel te evalueren op geschiktheid voor 3D-printen. Als we kijken naar de beeldverhouding, vergelijken we de grootste afmeting van de onderdelen met de gebieden met de kleinste afmetingen. Voor deze spuitgegoten behuizing zien we dat deze een vrij grote voetafdruk heeft, maar over dat grote gebied erg dun is. Plaatwerk en spuitgietonderdelen zijn zeer specifieke voorbeelden van dit soort geometrie, maar er zijn er nog veel meer. Onderdelen met hoge aspectverhoudingen zijn meestal erg dun, maar toch lang of breed en lopen een groter risico op kromtrekken, omvallen tijdens het afdrukken of op een andere manier zonder succes. Het opnieuw ontwerpen van deze onderdelen om meer solide of substantiële geometrieën te hebben, is meestal een goed idee.

☰ C1.7 - Common Manufacturing Applications



Module Review

 Markforged University

- **Module Review**

Mark all of the following that represent common manufacturing applications of Markforged composite 3D printed parts.

- Sand casting crucibles for containing molten steel
- Prototyping for injection molded parts
- Fixtures for component assembly
- Tooling and workholding
- Workplace organization tools

Correct



Click on a component in this image of an industrial sensor that could be a good application for a 3D printed part.



Correct



Which is a likely example of a non-ideal potential application of 3D printing with Markforged?

- A complex assembly fixture that was previously made from aluminum
- A tool holder for a pair of pliers to keep a work cell organized
- A prototype of a large, thin injection molded shell with flexible latches in different axes
- A pair of grippers for a cooperative industrial robot for a new product line

Correct



True/False: You've designed a tool that's an assembly of custom parts, plus some nuts and bolts and a pair of linear rails for part of the tool to slide on. You have the CAD for every component and should 3D print the entire tool because that's the easiest way to produce a functional part.

- True
- False

Correct



## Results

Your Score: 100% (40 points)  
Passing Score: 80% (32 points)

---

### Result:



Congratulations, you passed.


[Finish Module](#)

[Review Quiz](#)



C2.1 – Welcome to Essential Composites

☰ C2.1 - Welcome to Essential Composites RESOURCES



Markforged University – Composites Training Program

# Welcome to Essential Composites

- **Welcome to Essential Composites**

☰ C2.1 - Welcome to Essential Composites

## Crawl, Walk, Run



 Markforged University

- **Crawl, Walk, Run**

## Where are we going?

A replicable, robust **framework** for **identifying, justifying** and **executing** on AM opportunities in your work

**Best practices** for designing parts that reflect AM's unique **capabilities** and **limitations**

**Hands-on practice** working through example case studies on **AM adoption**

Finish Module

- **Where are we going?**

## C2.2 – Fiber Reinforcement Strategies



- **Fiber Reinforcement Strategies**

☰ C2.2 - Fiber Reinforcement Strategies

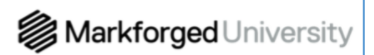
## Module Overview

CFF Strength Demo

Beam Bending Theory

Mechanics of Composite Reinforcement

Activity: Reinforcement Strategies in Eiger



- **Module Overview**

☰ C2.2 - Fiber Reinforcement Strategies

RESOURCES



- **Video: The True Strength of Composites**





9980 kg [22,000 pounds] is...

One Unloaded Cement Truck or...

Six 2009 Ford Tauruses or...

19 Grizzly Bears or...

1.6 T-Rexes or...

250 Toilets or...

1500 Bowling Balls

Source: [bluebulbprojects.com/measureofthings](http://bluebulbprojects.com/measureofthings)

- **What is 22,000 Pounds?**
  - [The Measure of Things](#)

Continuous Fiber is strong in TENSION



- **Continuous Fiber is strong in TENSION.**



## Continuous Fiber is strong in TENSION

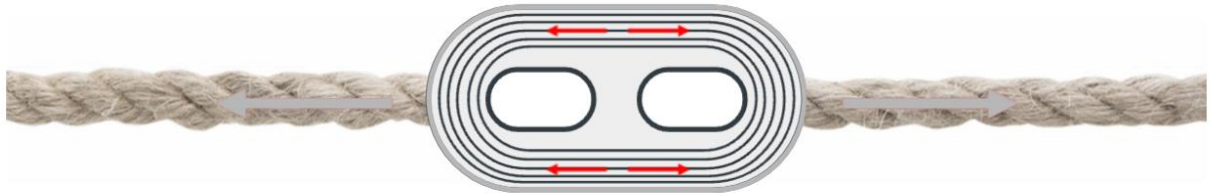


**Stuck?**  
Click on the rope to see a comparison between a rope under tension and the chain link in the tensile tester.

## Continuous Fiber is strong in TENSION



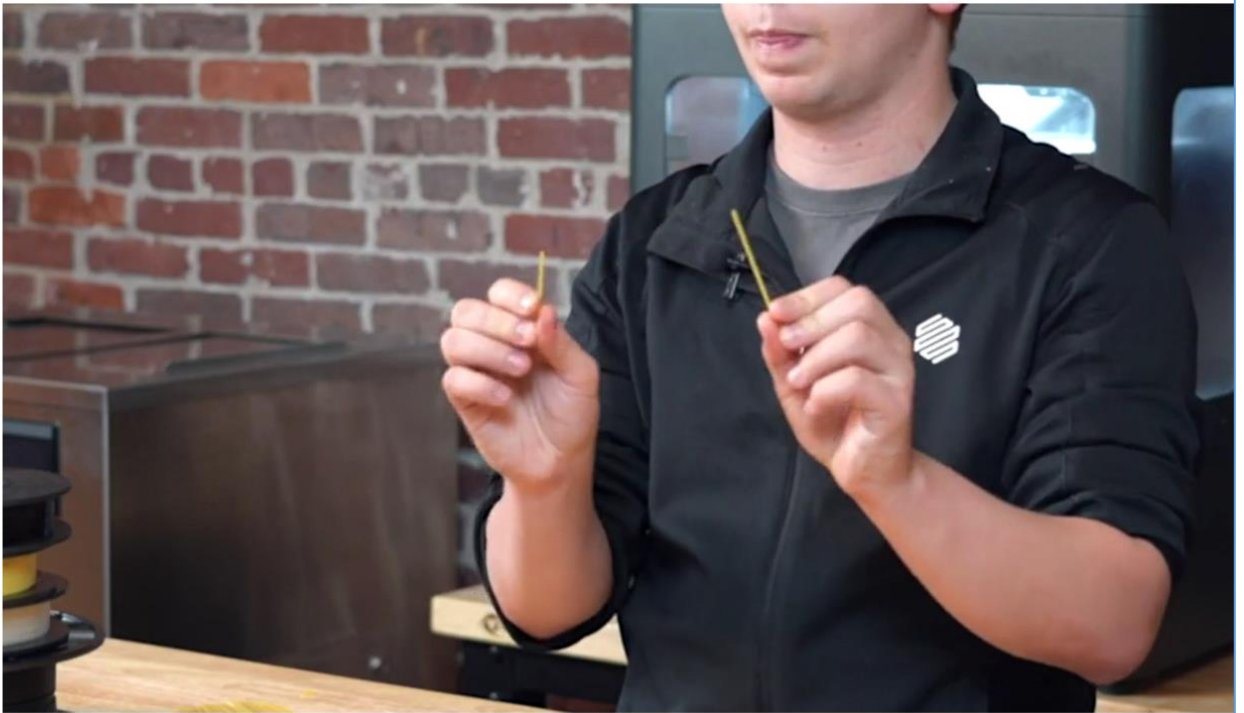
## Continuous Fiber is strong in TENSION



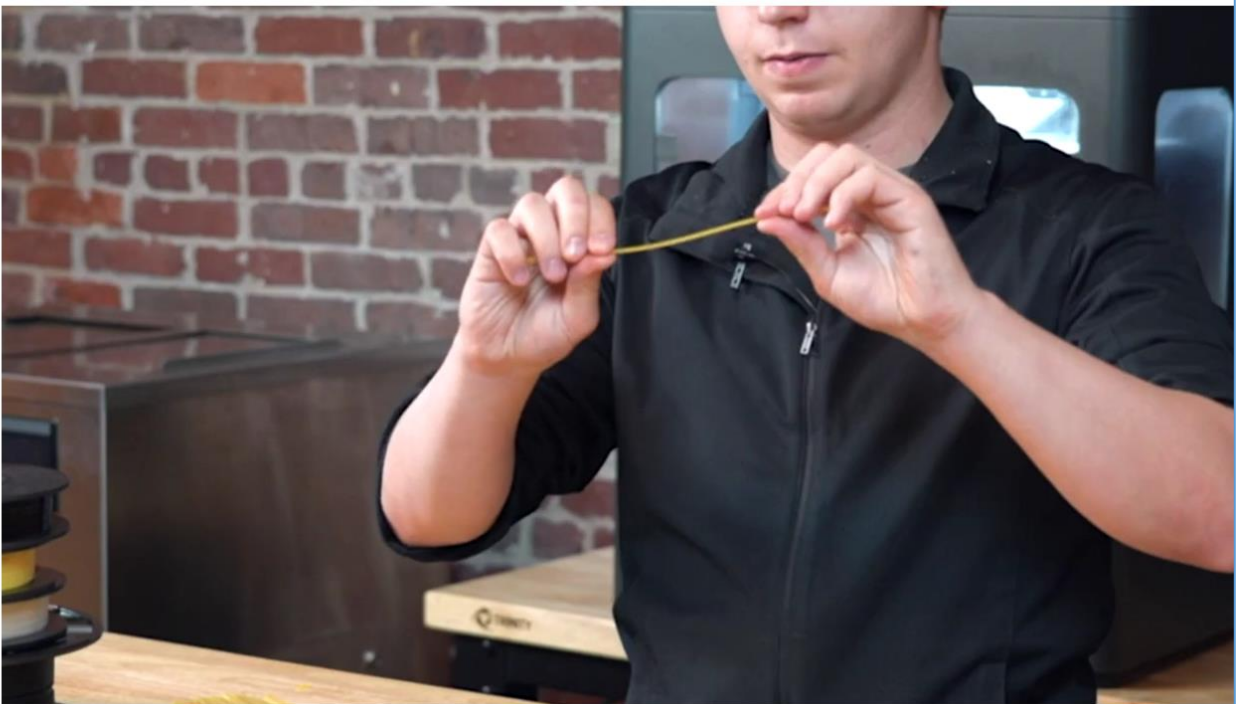
## ACTIVITY: Demonstrating Fiber Strengths & Weaknesses



- **Activity: How Fiber Reacts to Applied Loads**



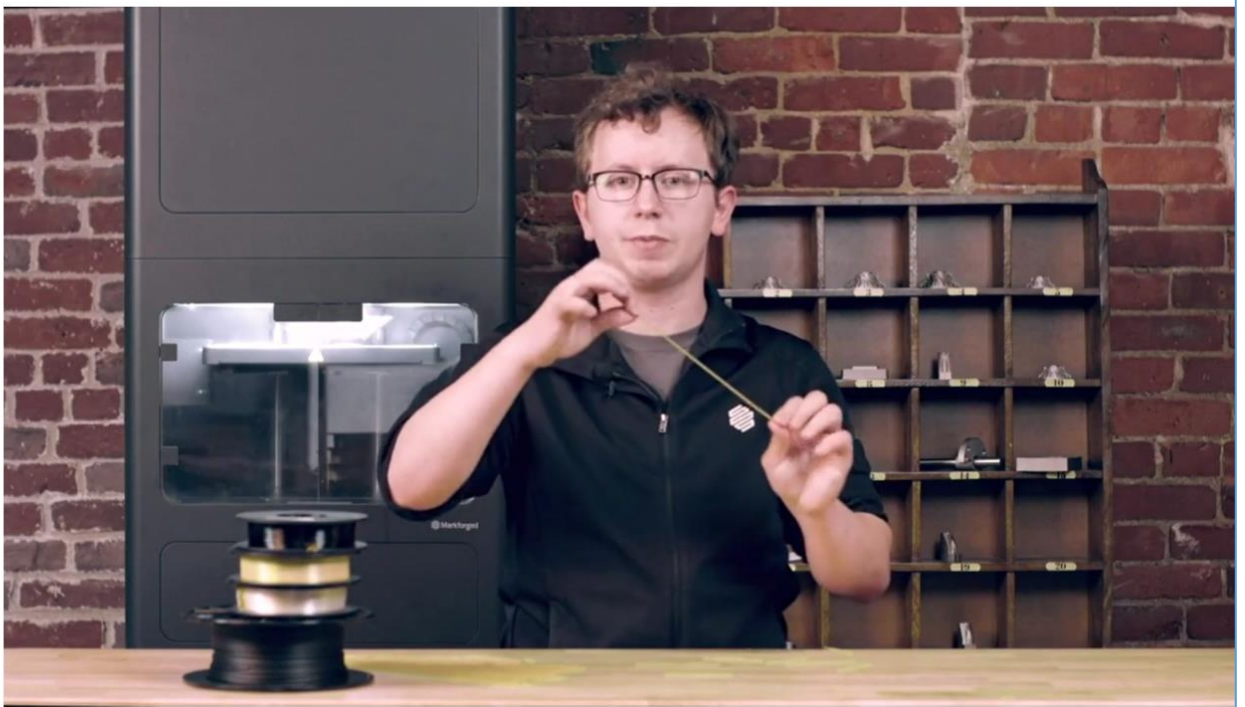
- Easily breaking by bending it.



- Easily breaking by compressing it.

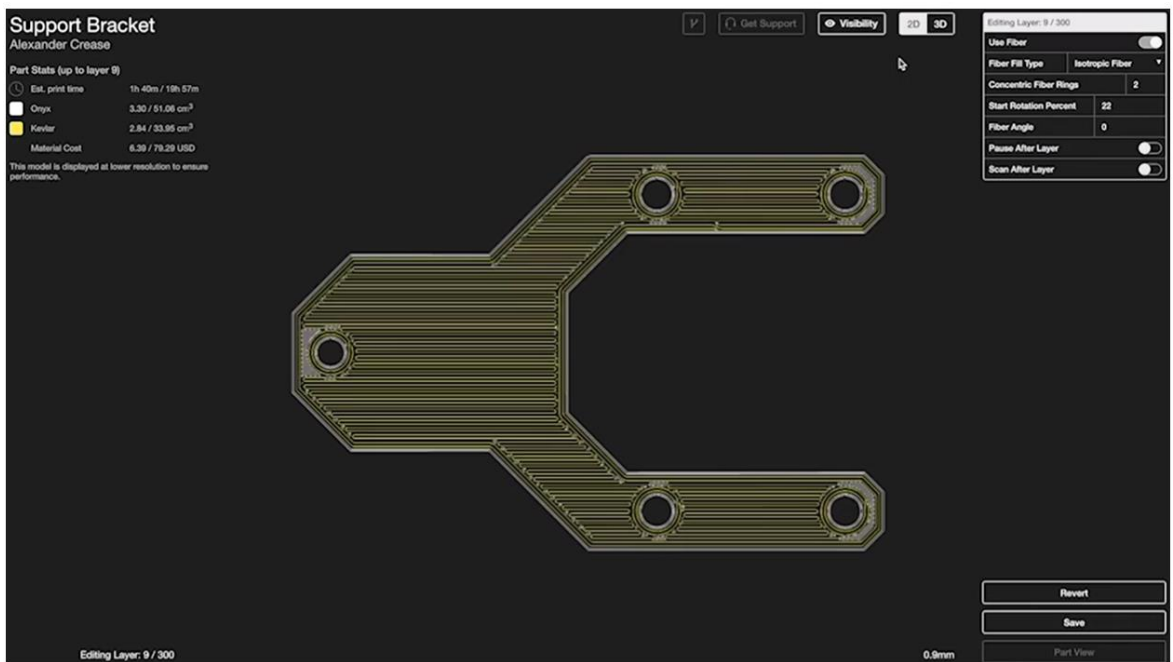
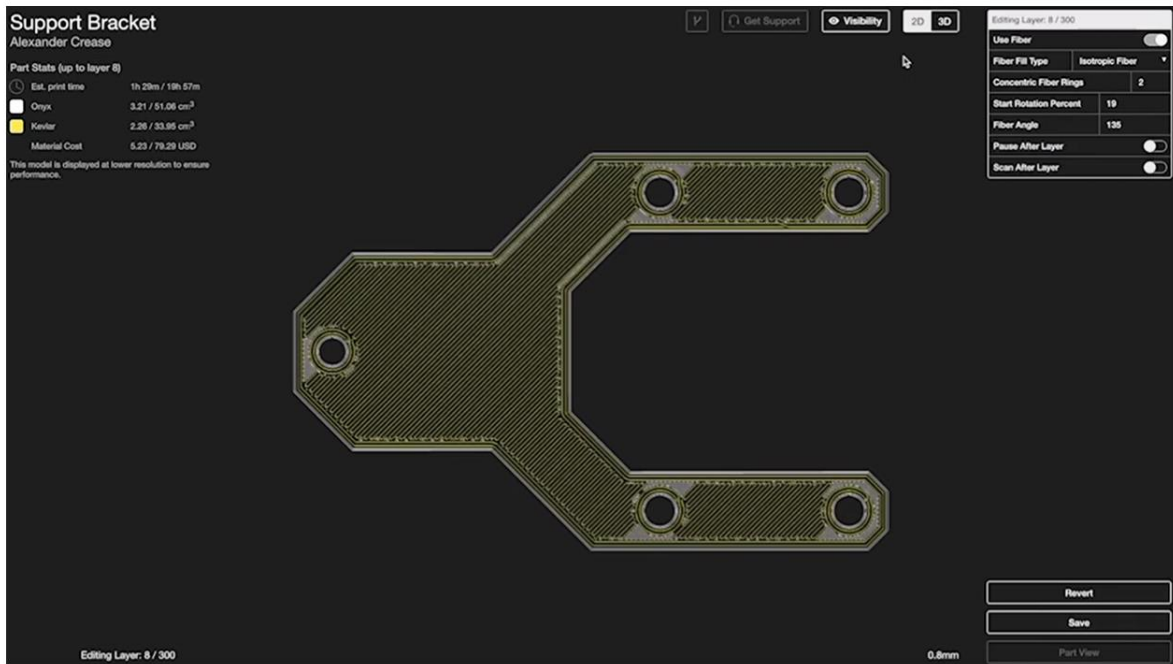


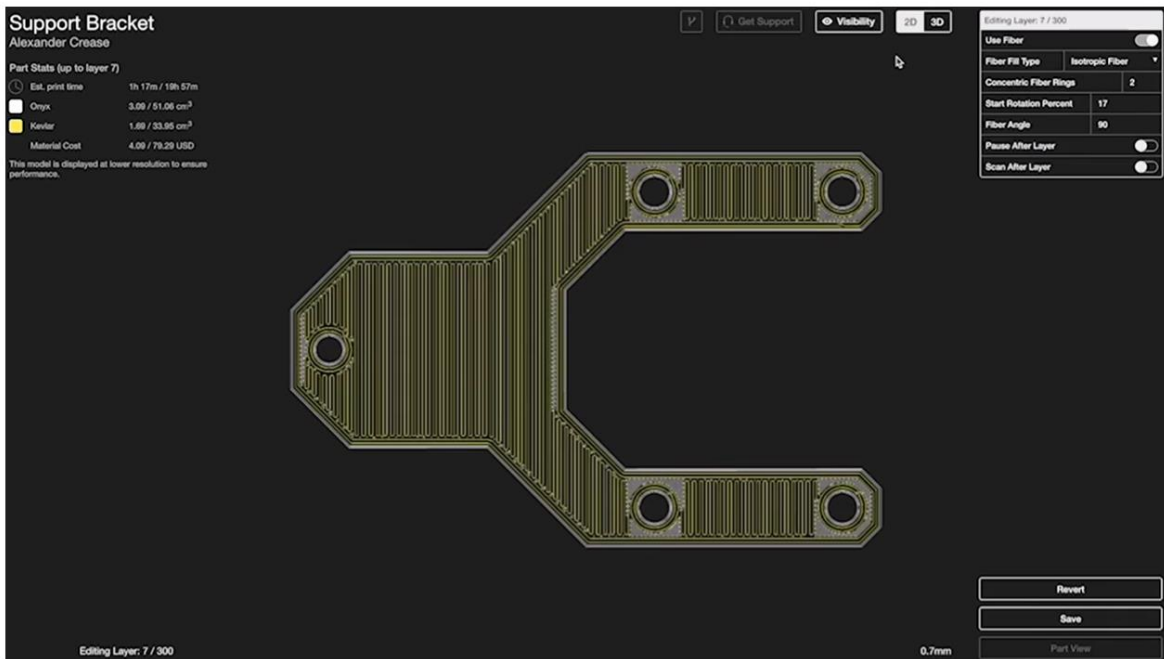
- Easily breaking by shearing it.



- But it takes lots of more force in tension by pulling on it.







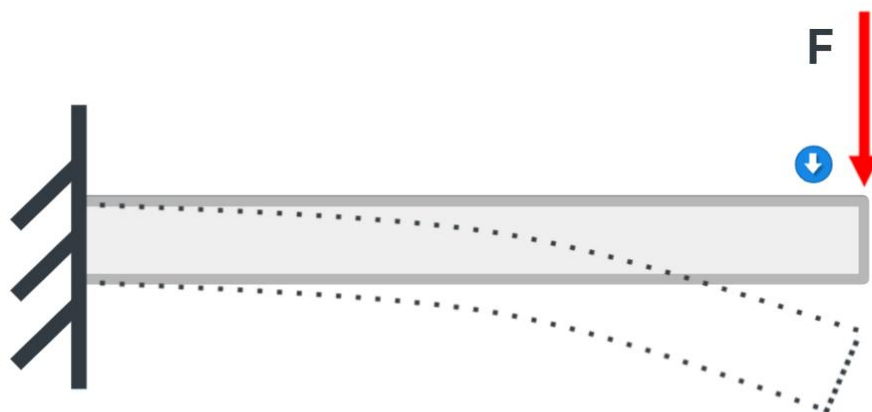


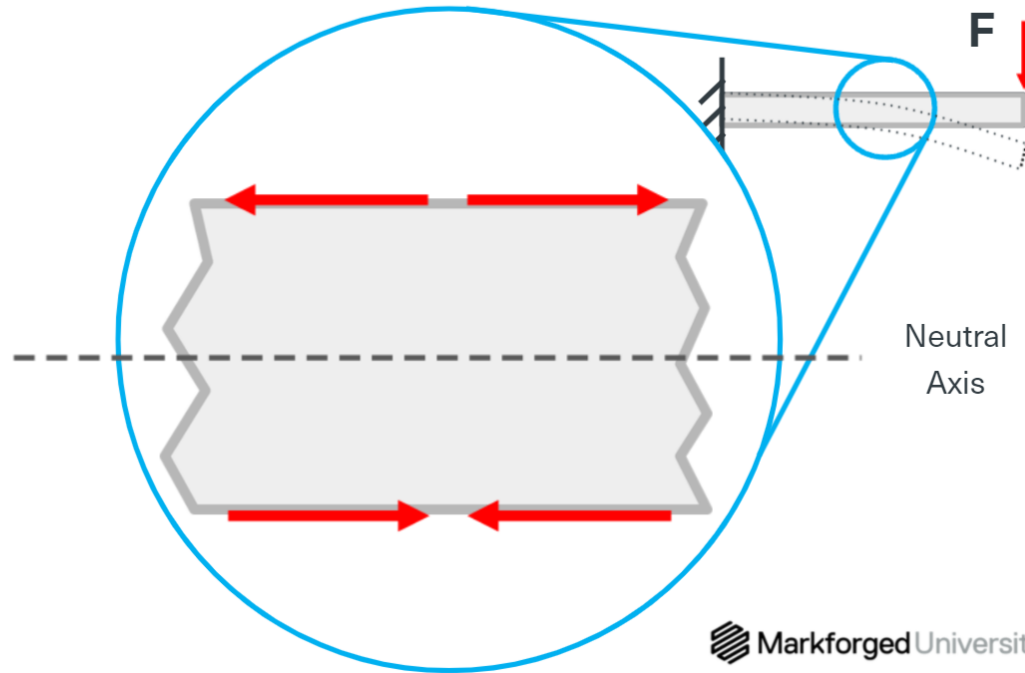
## Back to Basics: Beam Bending Theory



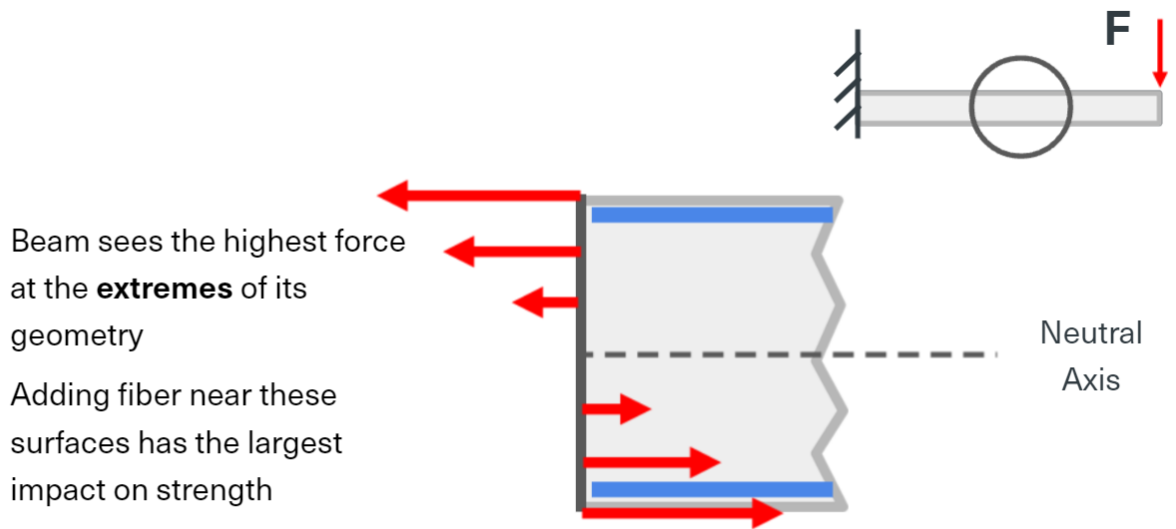
- **Back to basics: Beam Bending Theory**

## Back to Basics: Beam Bending Theory





- Internal Forces in a Beam



Beam sees the highest force at the **extremes** of its geometry

Adding fiber near these surfaces has the largest impact on strength

■ Carbon Fiber



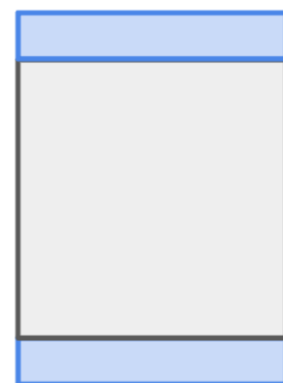
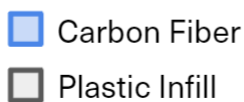
## Strategy: Add Fiber in Sandwich Panels



- **Add Fiber in Sandwich Panels**
  - Cheaper and faster printing, by using composite fiber sparsely, by adding in areas who has the most impact.

## What is a Sandwich Panel?

Composed of a low density infill **sandwiched** between two high strength/stiffness panels  
Outer panels usually much thinner than infill structure



- **What is a Sandwich Panel?**
  - Keeping down cost and weight.

- Low infill structure (low density) with solid onyx-skin.

## What is a Sandwich Panel?

Composed of a low density infill  
**sandwiched** between two high  
strength/stiffness panels

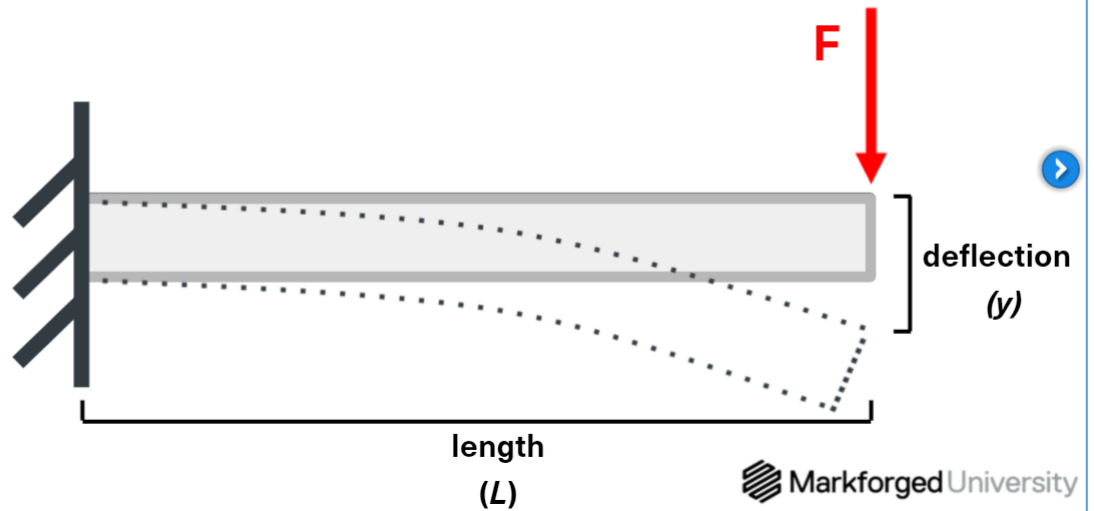
Outer panels usually much thinner  
than infill structure

- Carbon Fiber
- Plastic Infill



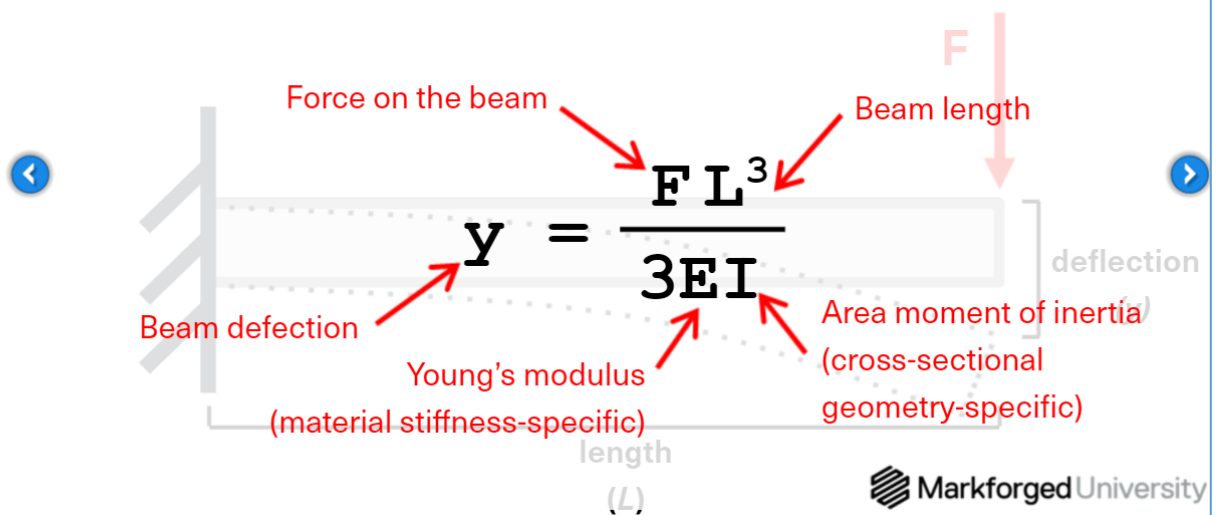
- An Example of a Sandwich Panel is an I-beam.

## Beam Thickness Drives Stiffness

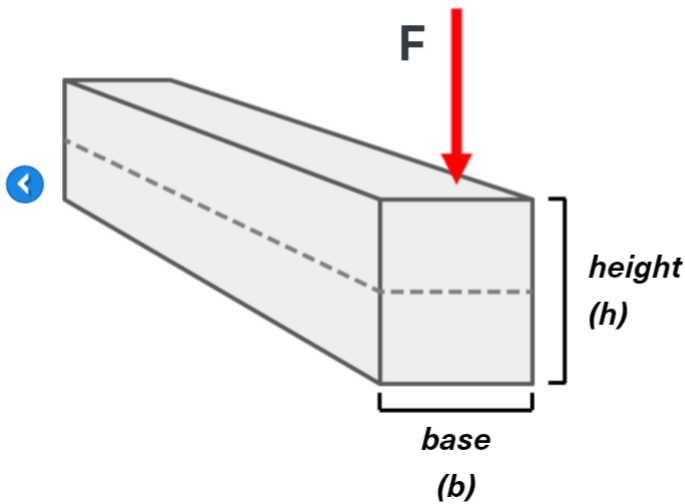


- **Beam Thickness matters**

## For a Rectangular Cross-Section Beam:



### Beam Stiffness $\sim bh^3$



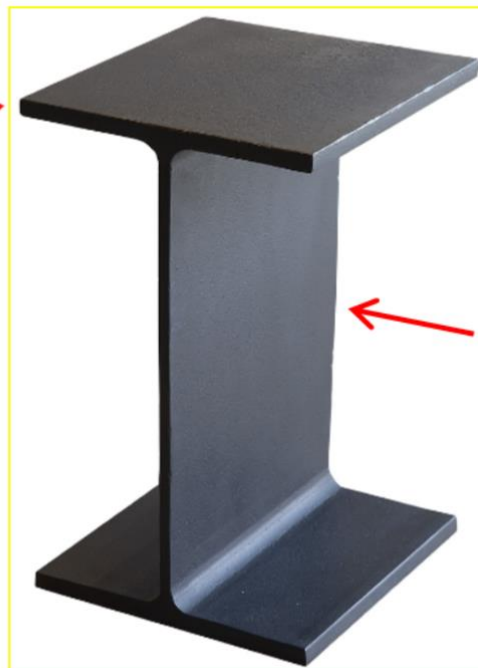
Area Moment of Inertia,  
Rectangular Cross Section:

$$I = bh^3/12$$

All else equal:

$$y \sim 1/bh^3$$

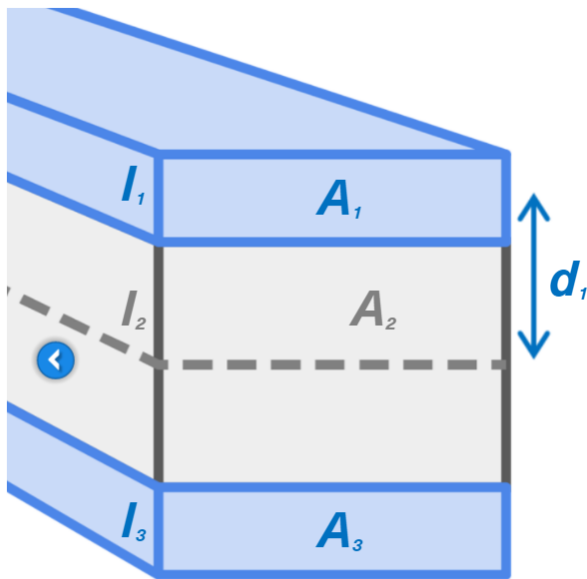
Maximal beam  
width furthest  
from centroid



Minimal material in  
central region

- Centroid = zwaartepunt





## Parallel Axis Theorem

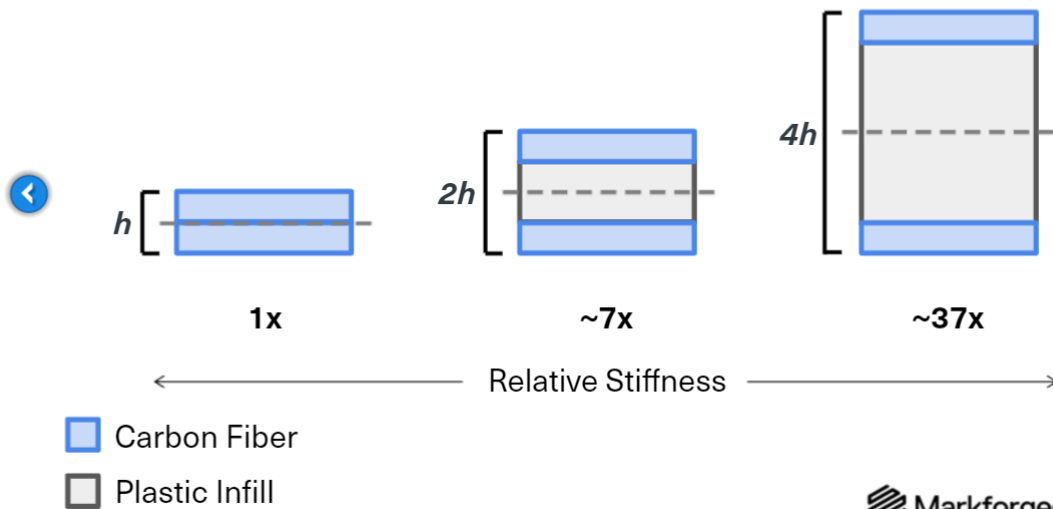
$$I_{\text{total}} = \sum (I_i + A_i d_i^2) \quad \text{where:}$$

$I_i$  = The moment of inertia of the individual segment about its own centroid axis

$A_i$  = The area of the individual segment

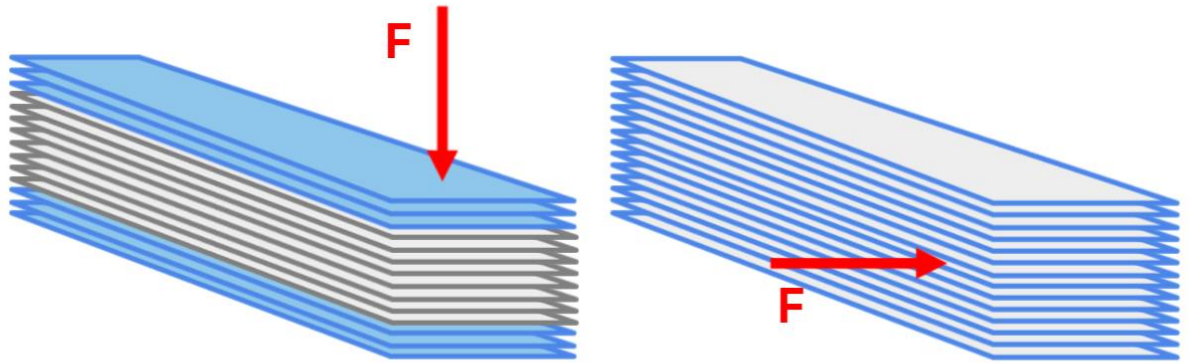
$d_i$  = The vertical distance from the centroid of the segment to the overall neutral axis

## Thickness Yields Material Efficiency

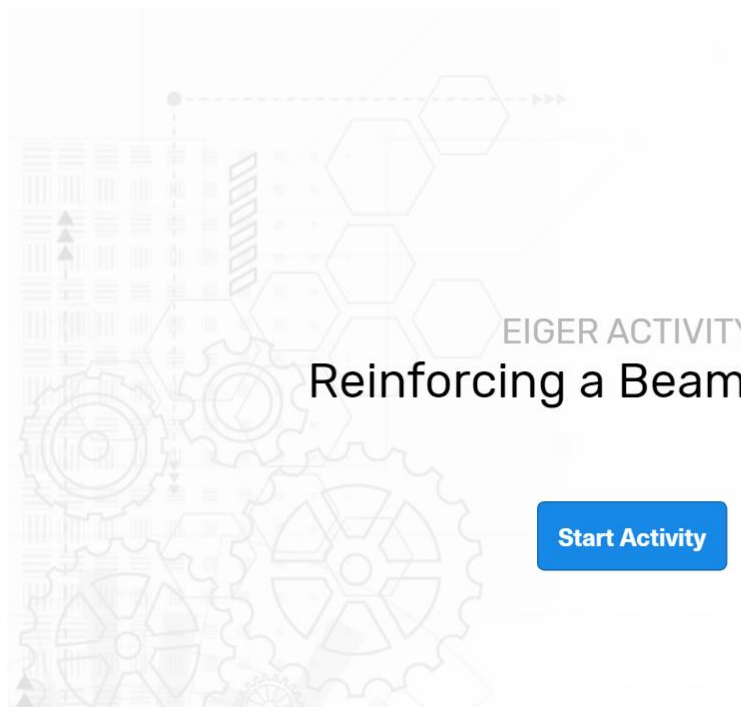


- Yield = Opbrenst.

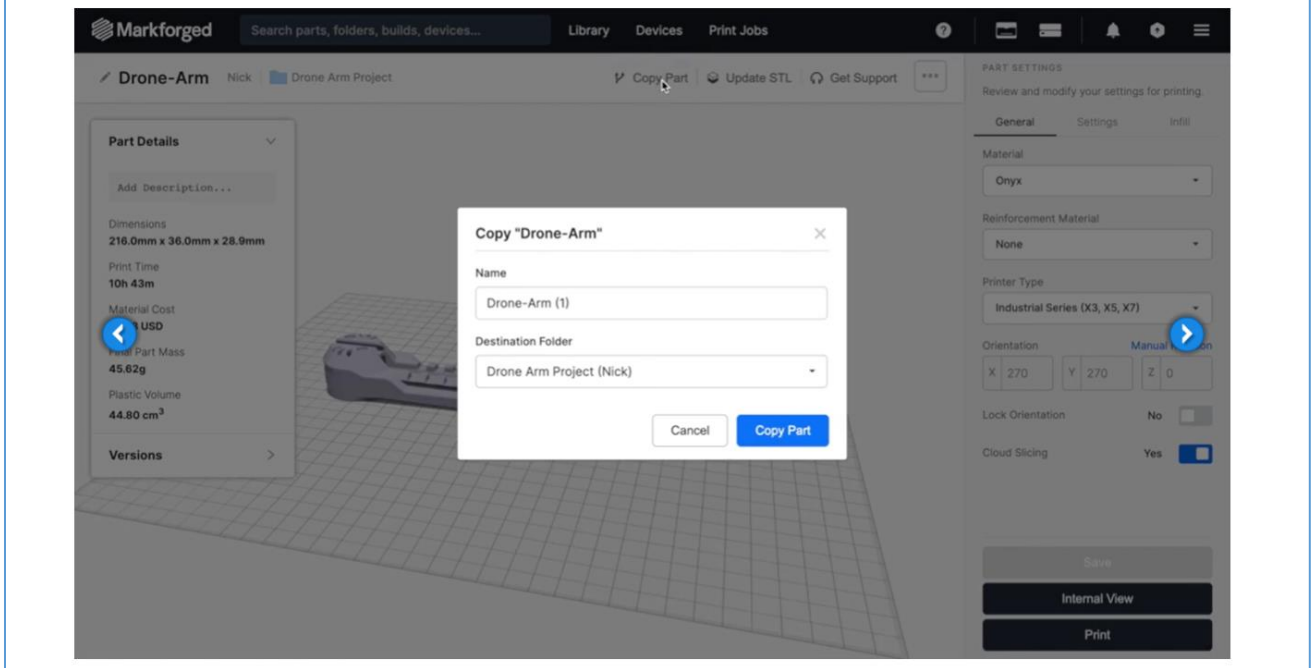
## Loading Conditions Drive Panel Location



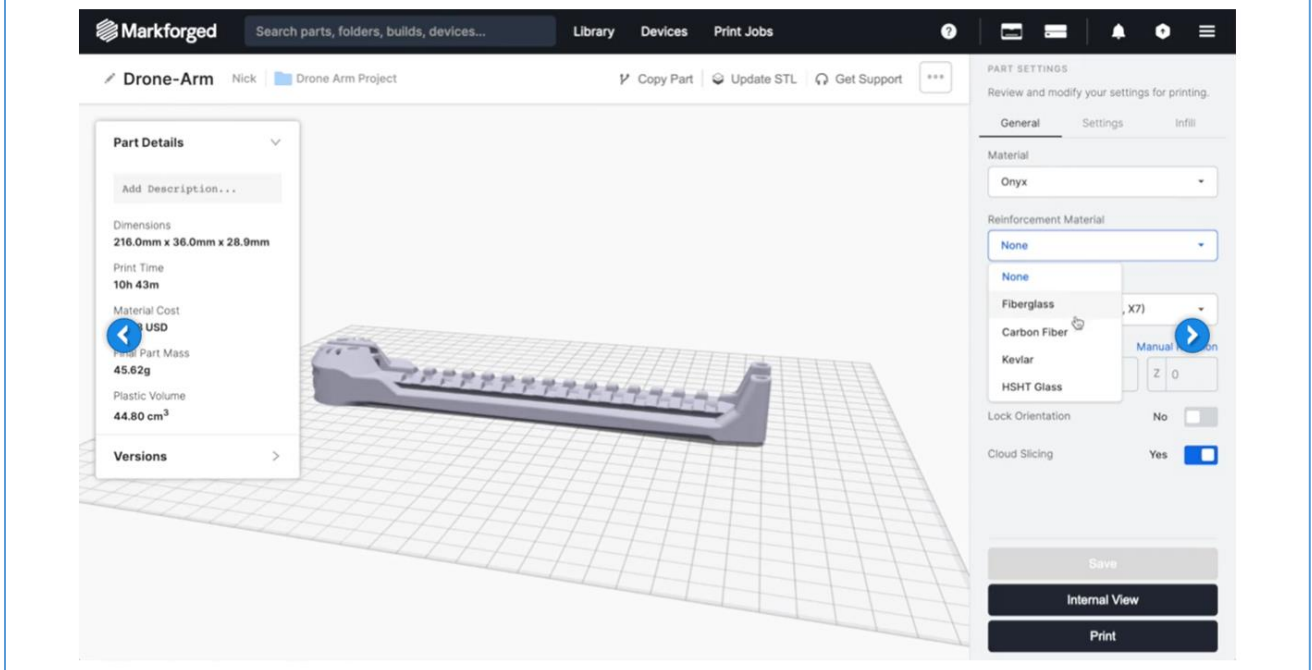
- **Loading Conditions Drive Reinforcement Location**



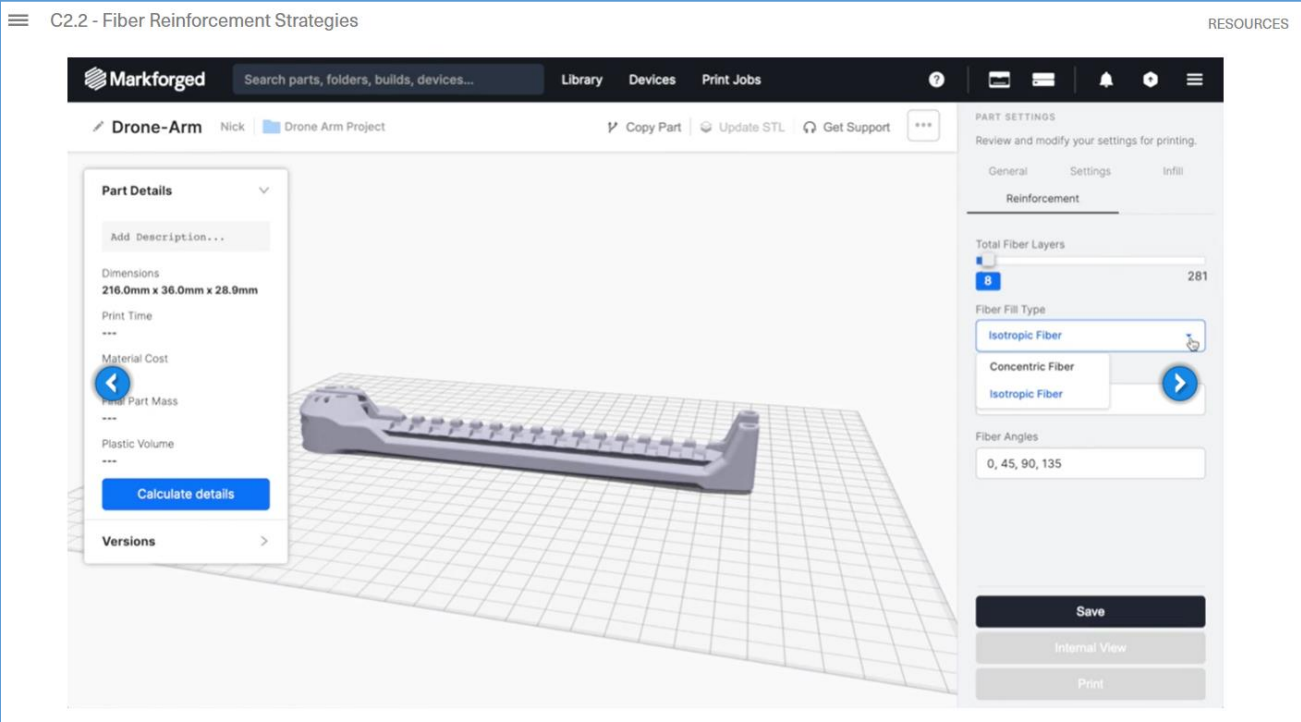
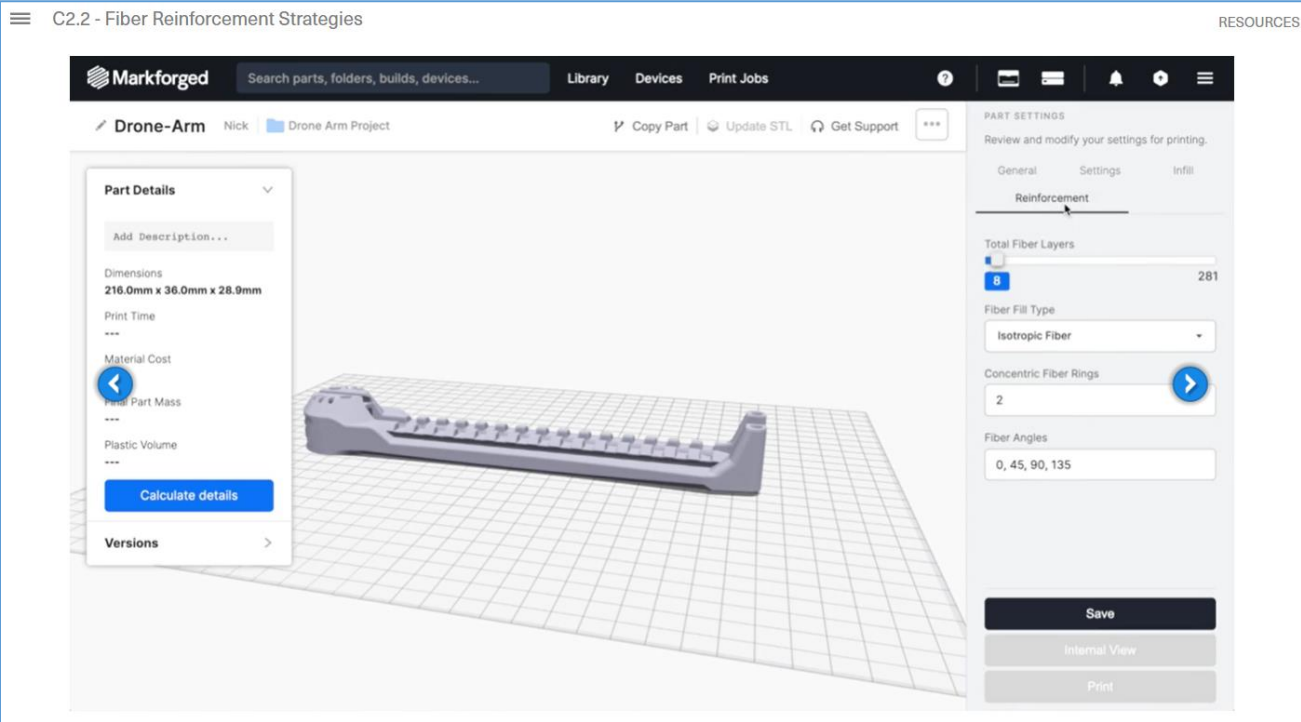
- **Activity: Reinforcing a Beam with CFF**



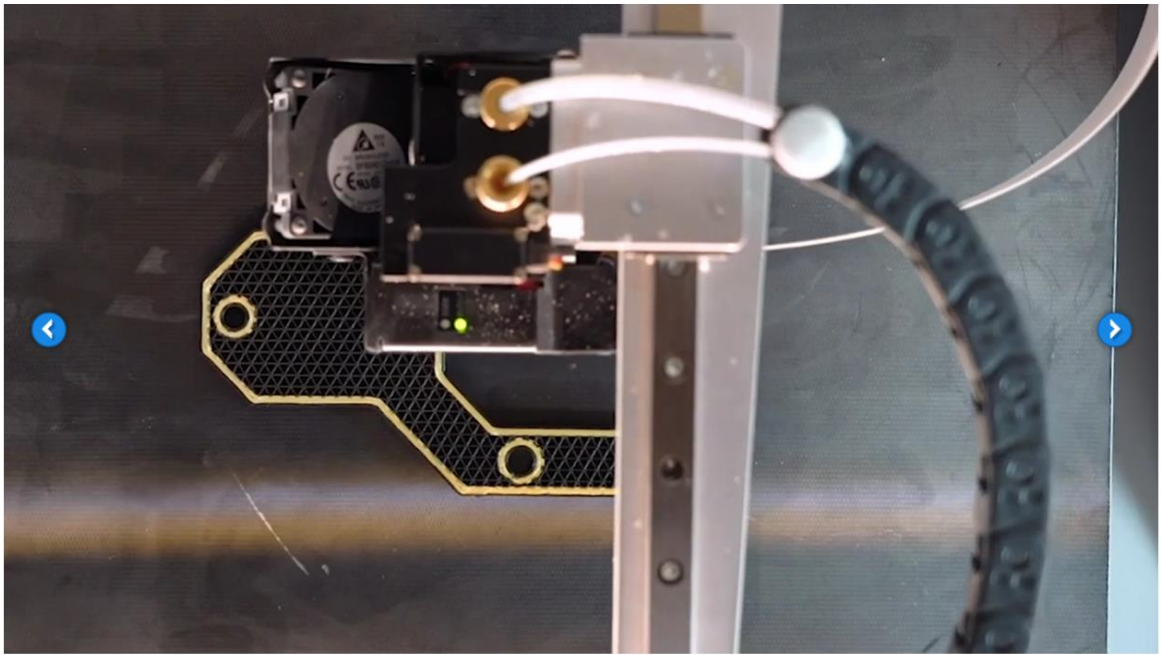
- Copy and new name.



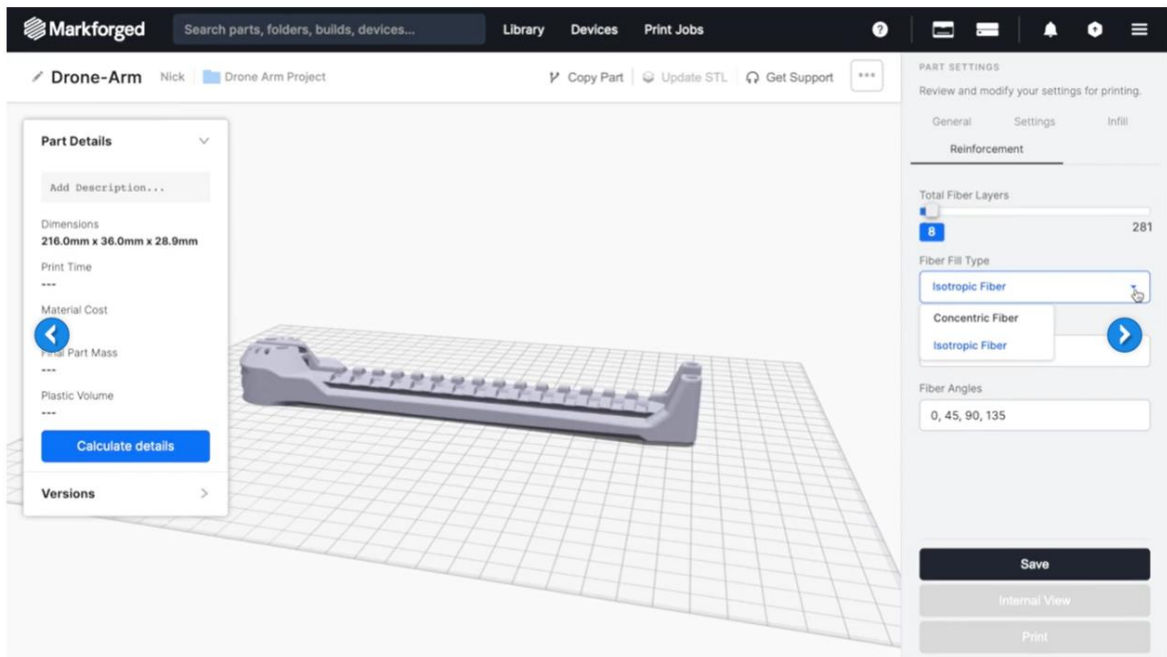
- Choose reinforcement material.
  - Note: Carbon prints thicker 125µm layerheight, than other fibers, that prints 100µm layerheight.



- Concentric Fiber

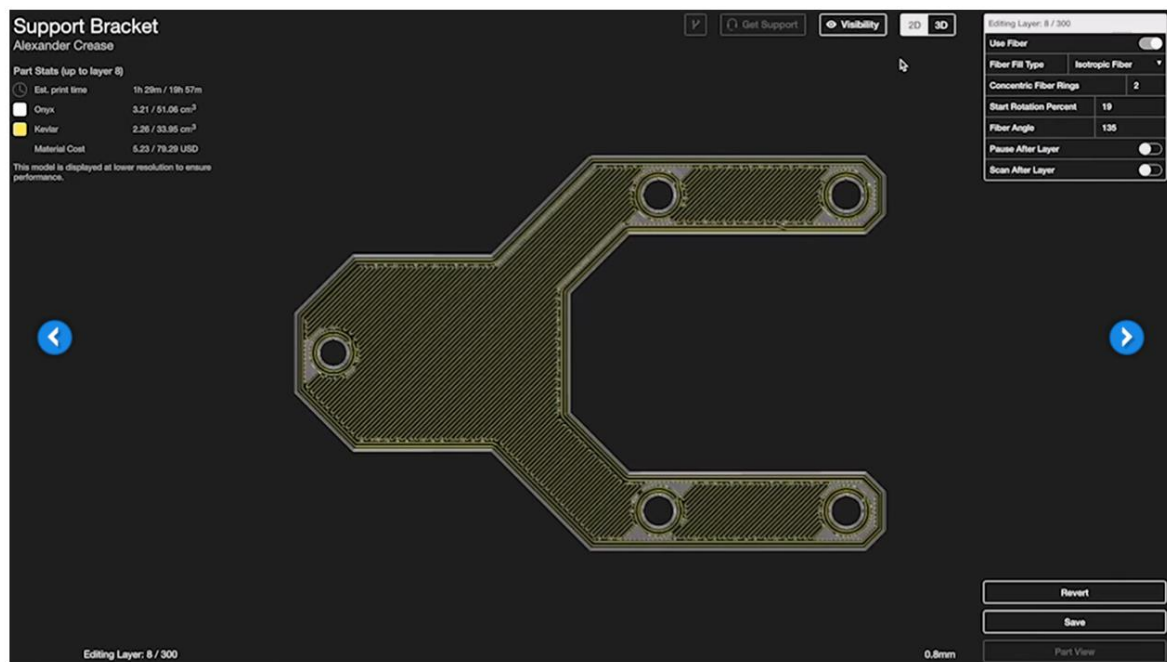
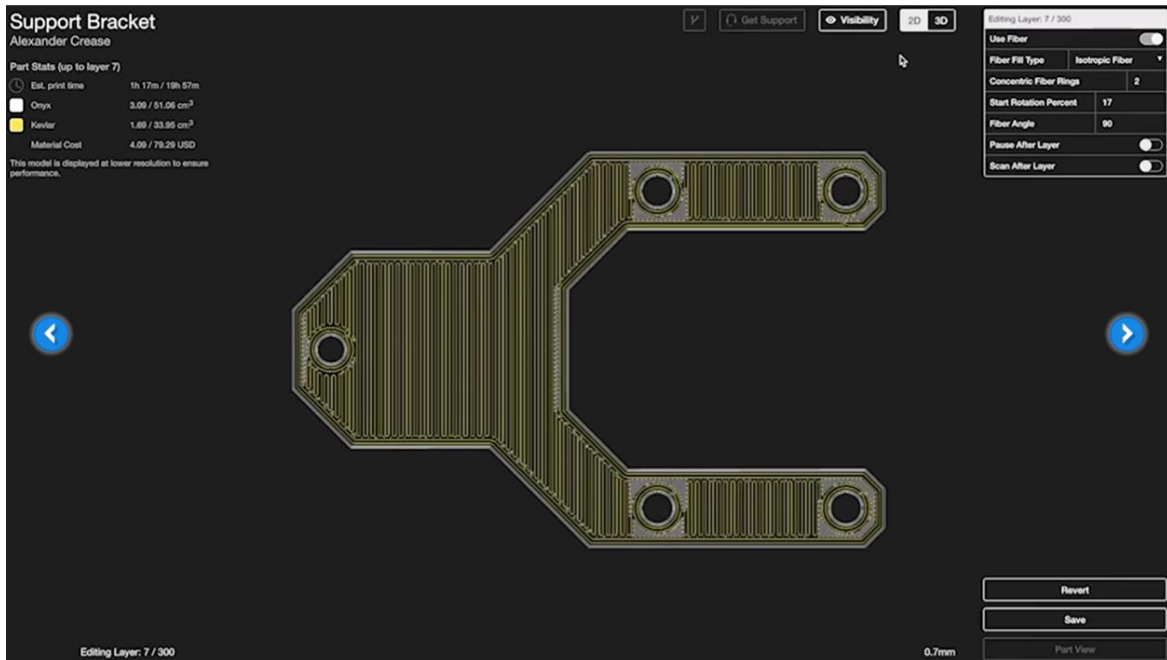


○ Concentric Fiber

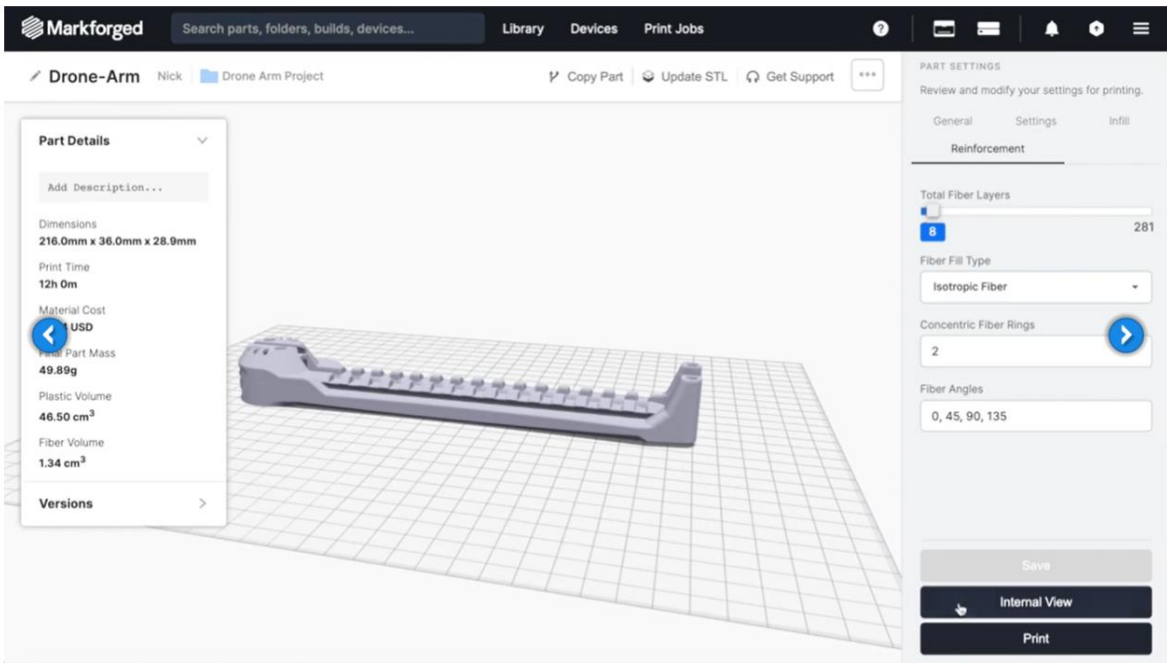
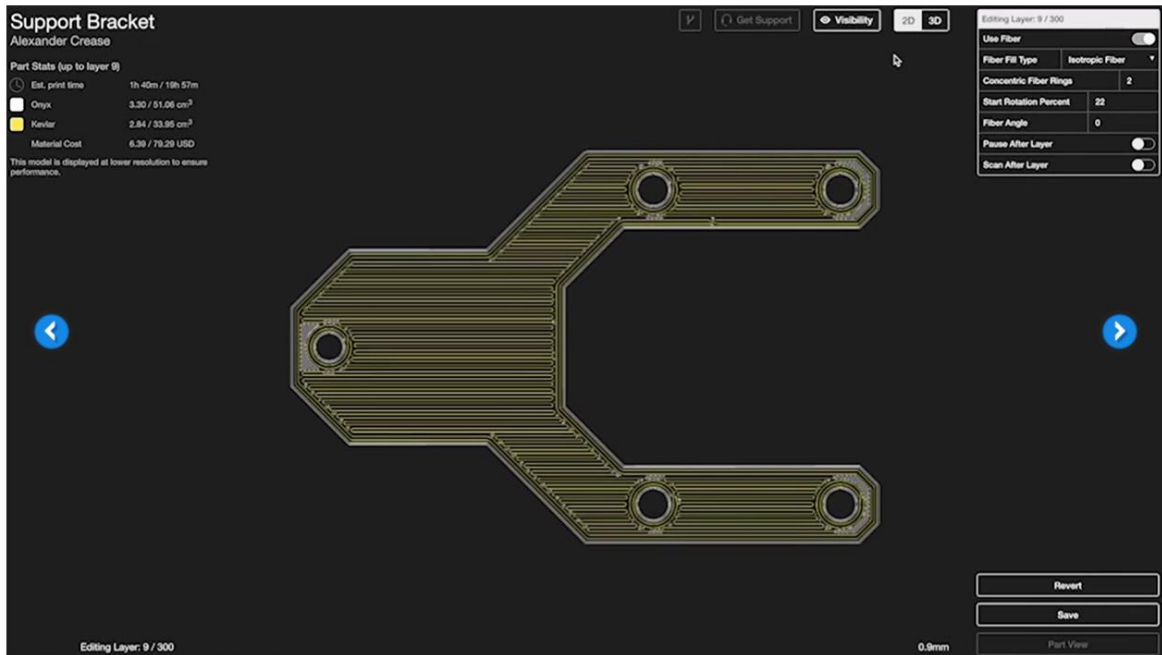


○ Isotropic Fiber

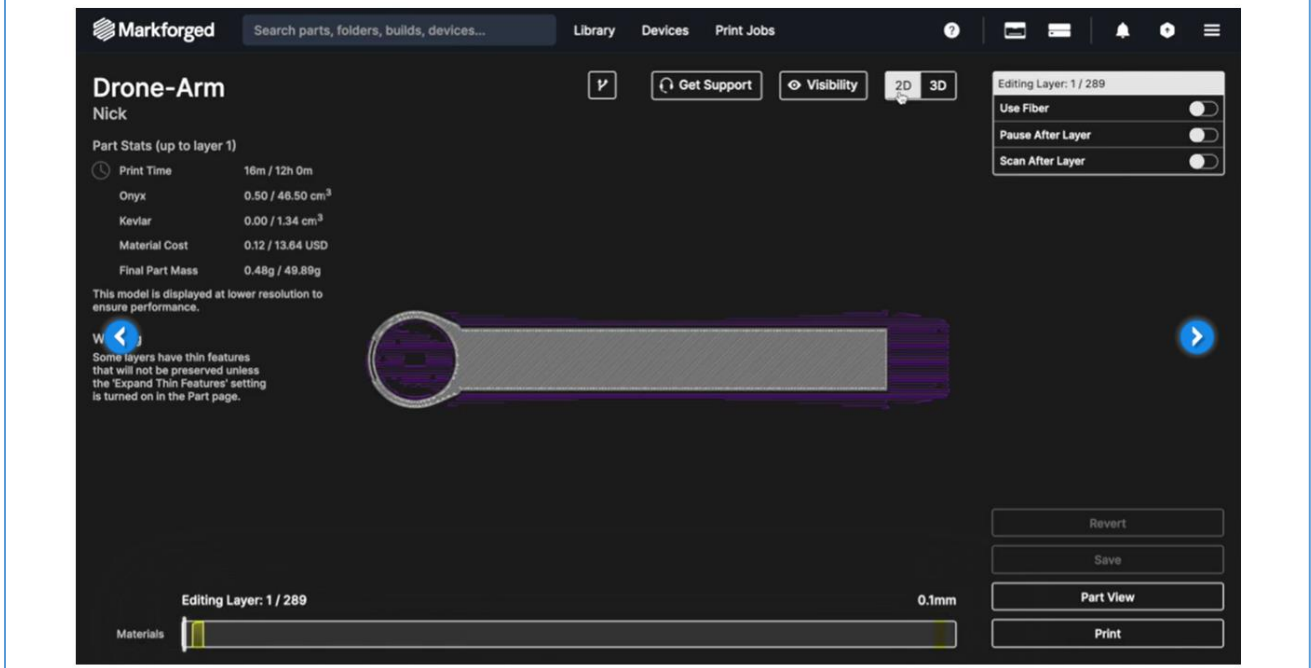
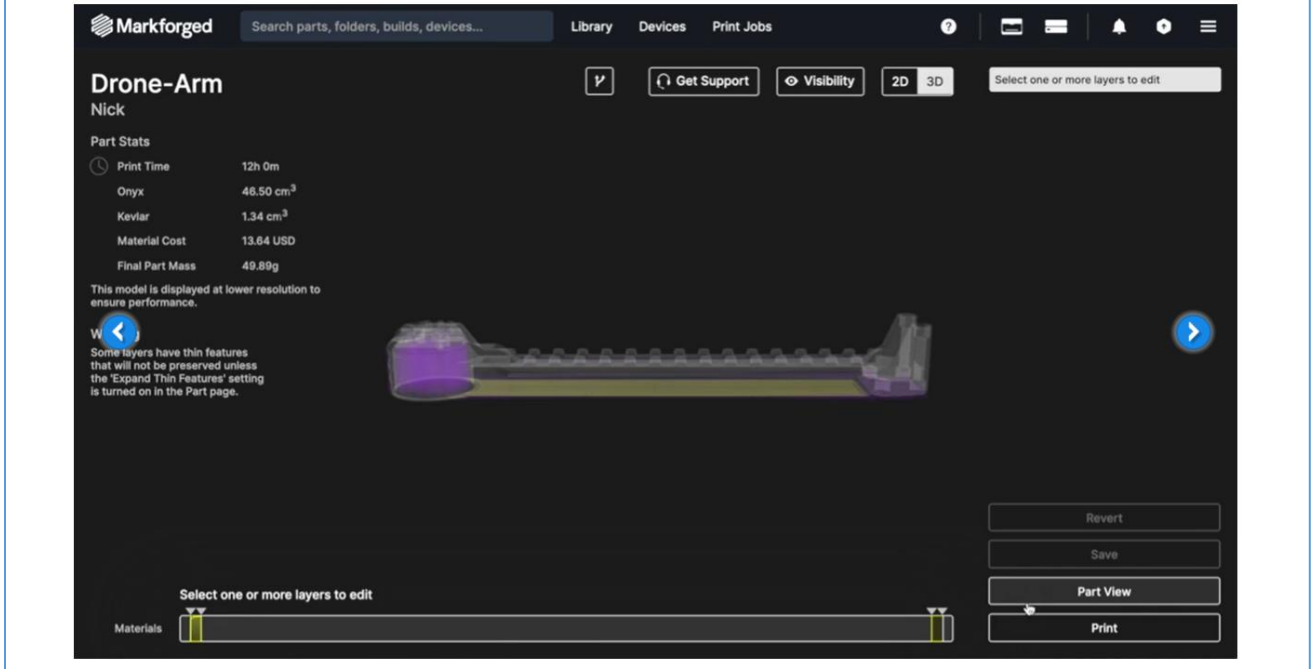
- Leads to more reinforcement material and printtime.



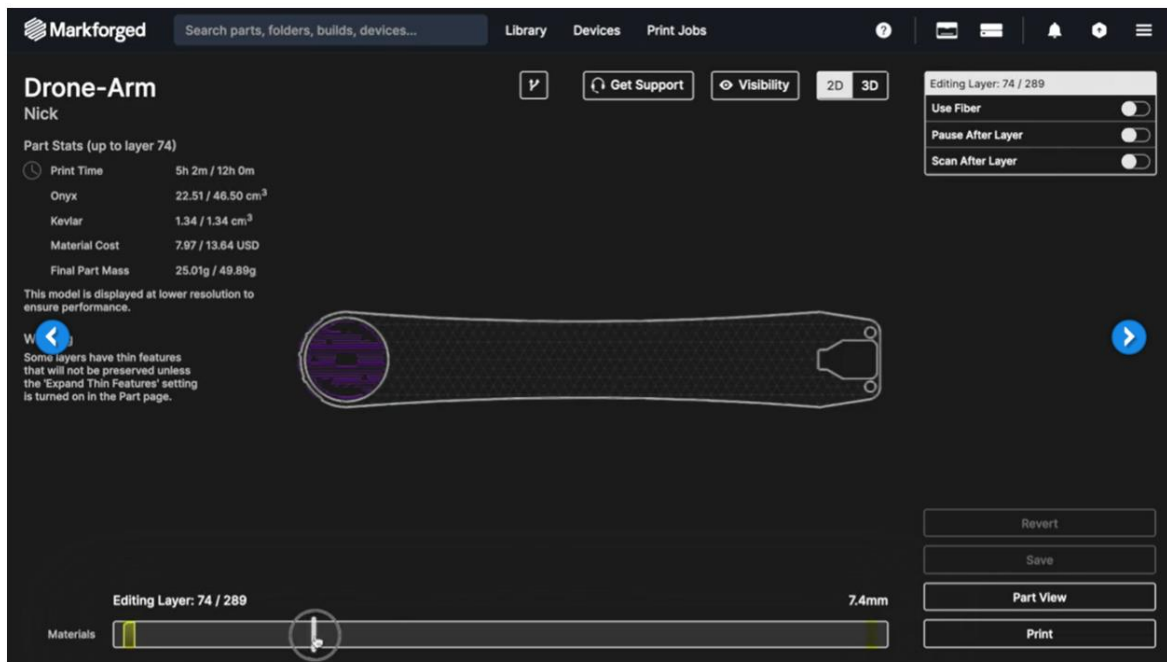
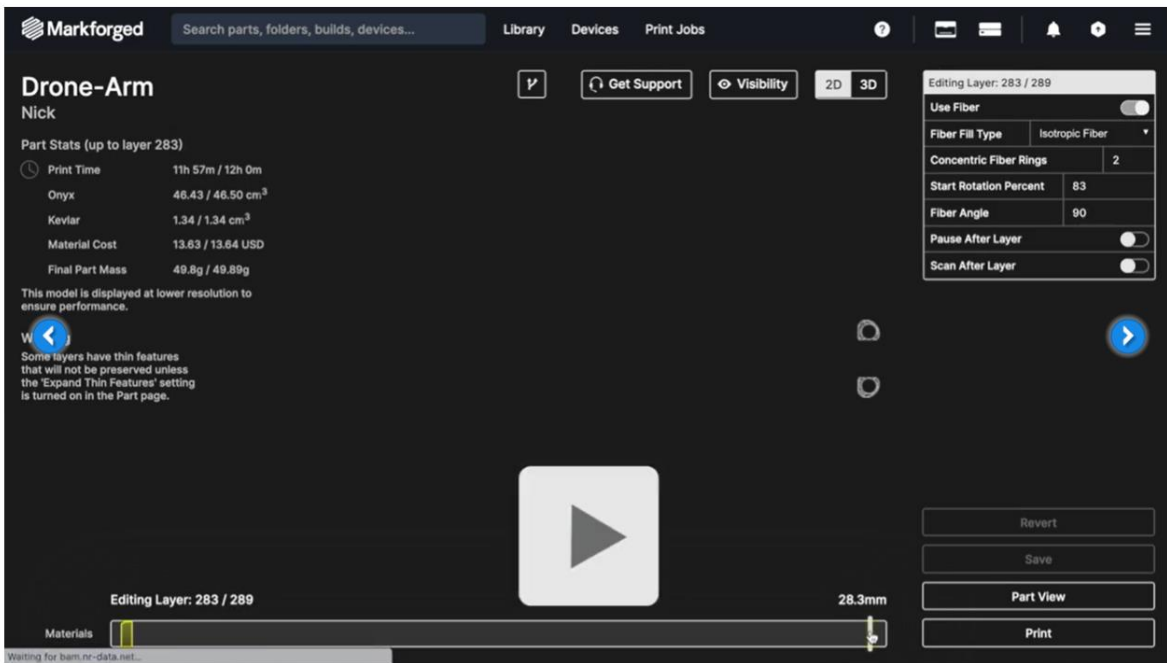




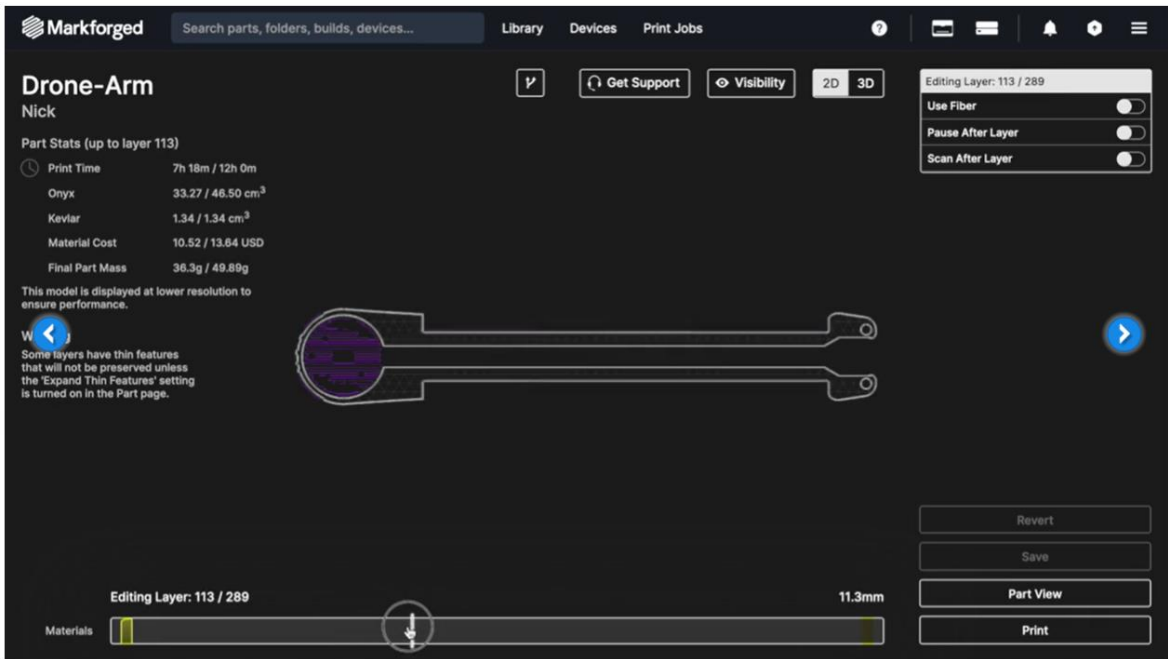
- Internal view: Click on Button Right beneath to get there.



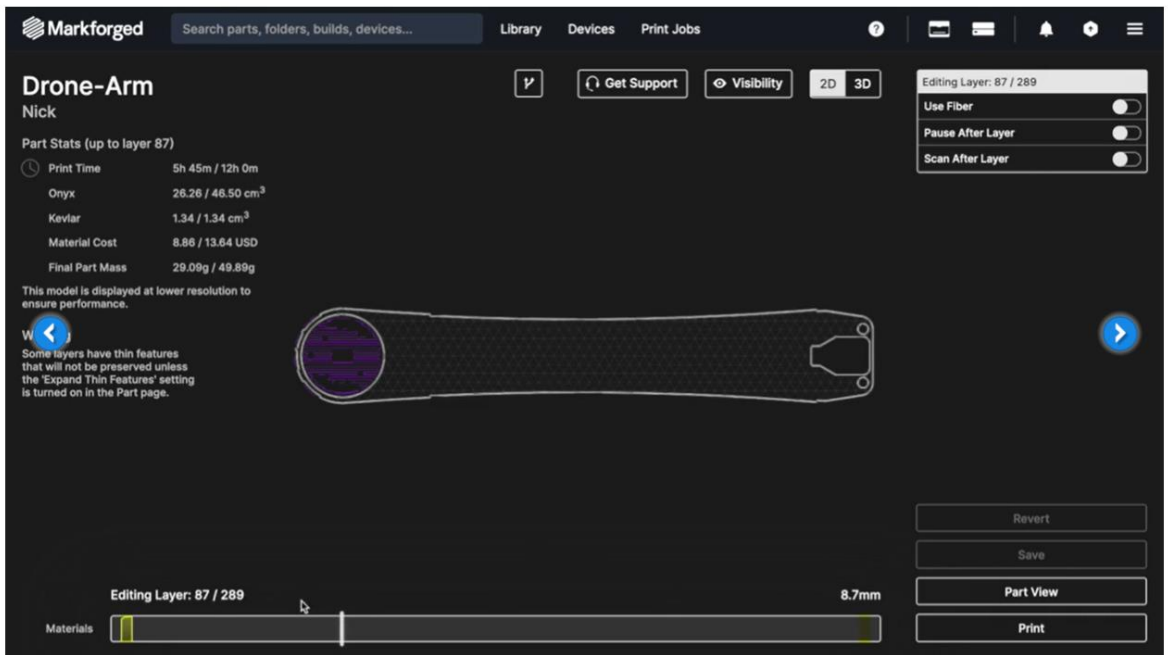
- 2D view.



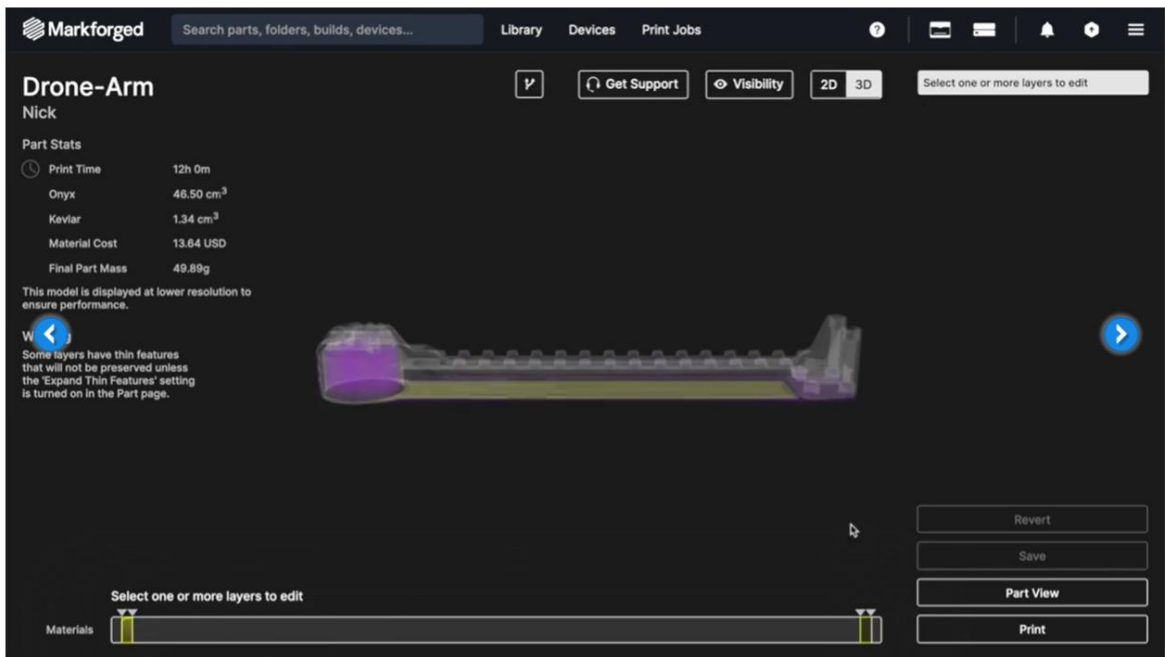
- Navigate down lower in the part.



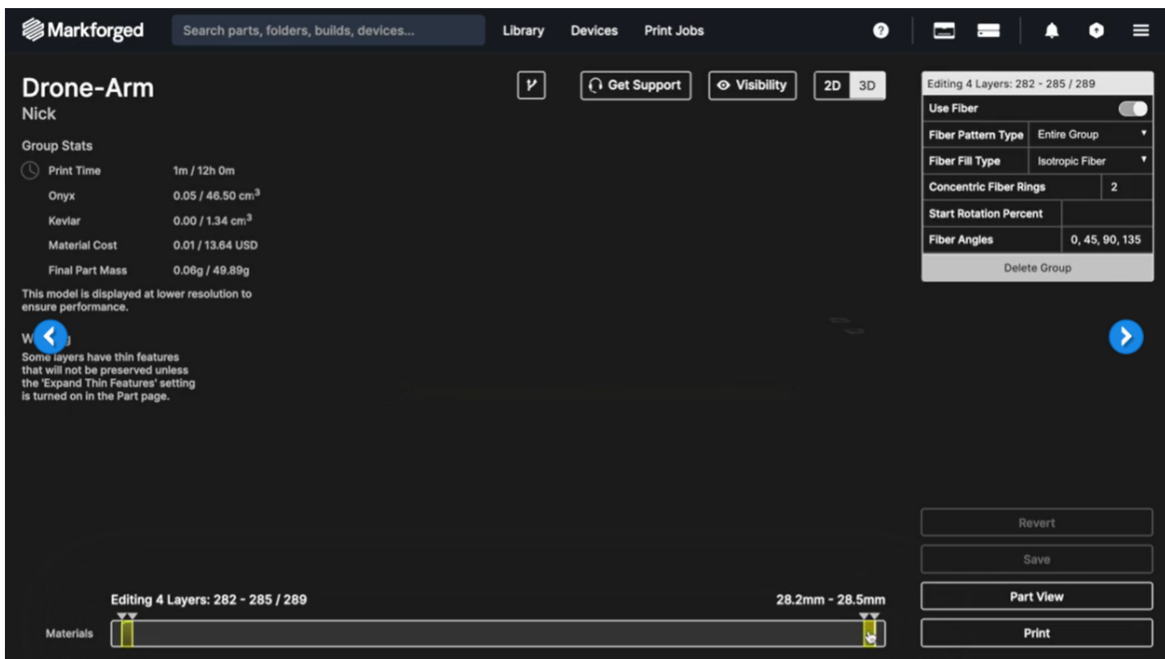
- For example: layer 113.



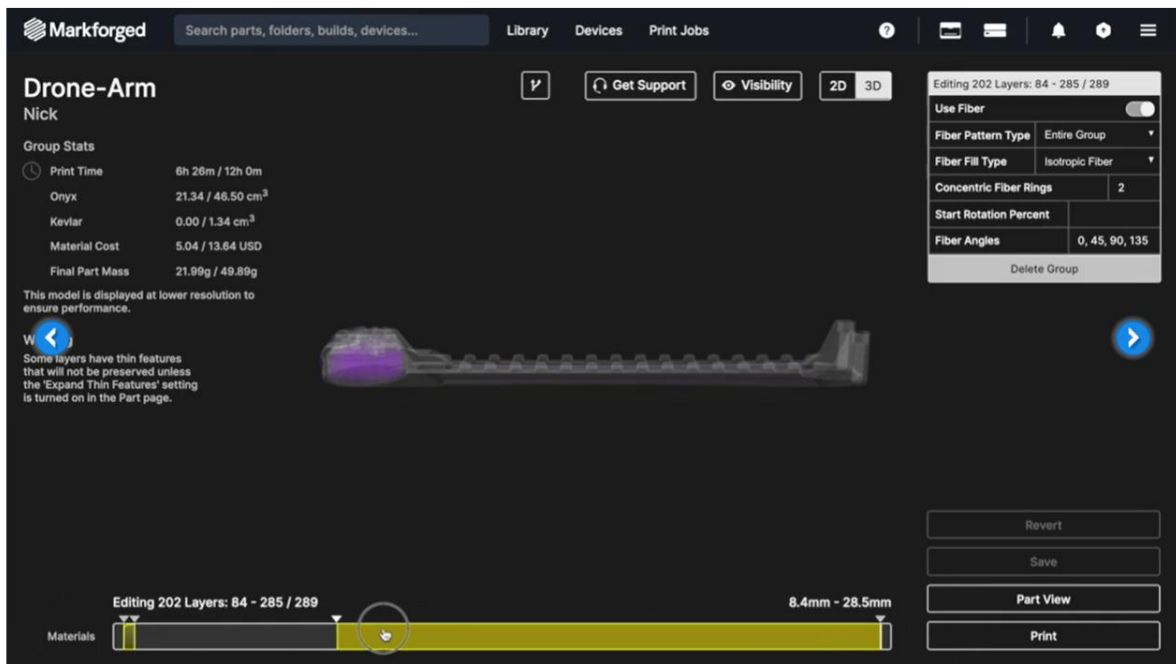
- The Layer beneath the first roof layer is (in this case) 87.



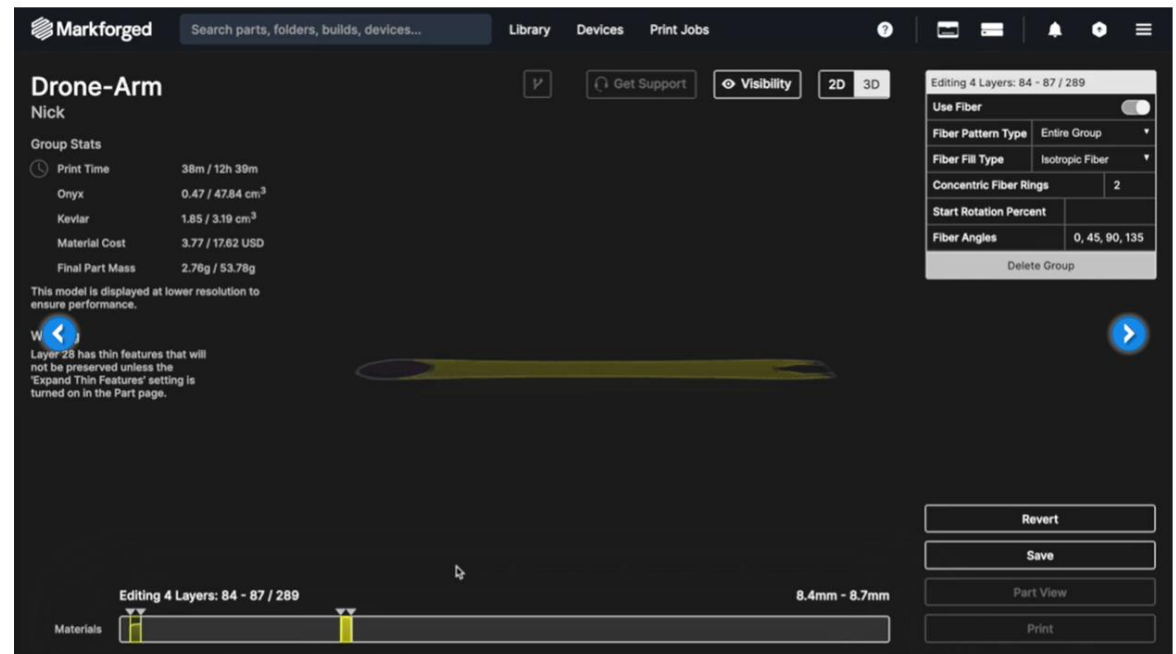
- Going back to the 3D layer view.



- Click on the top layer group.

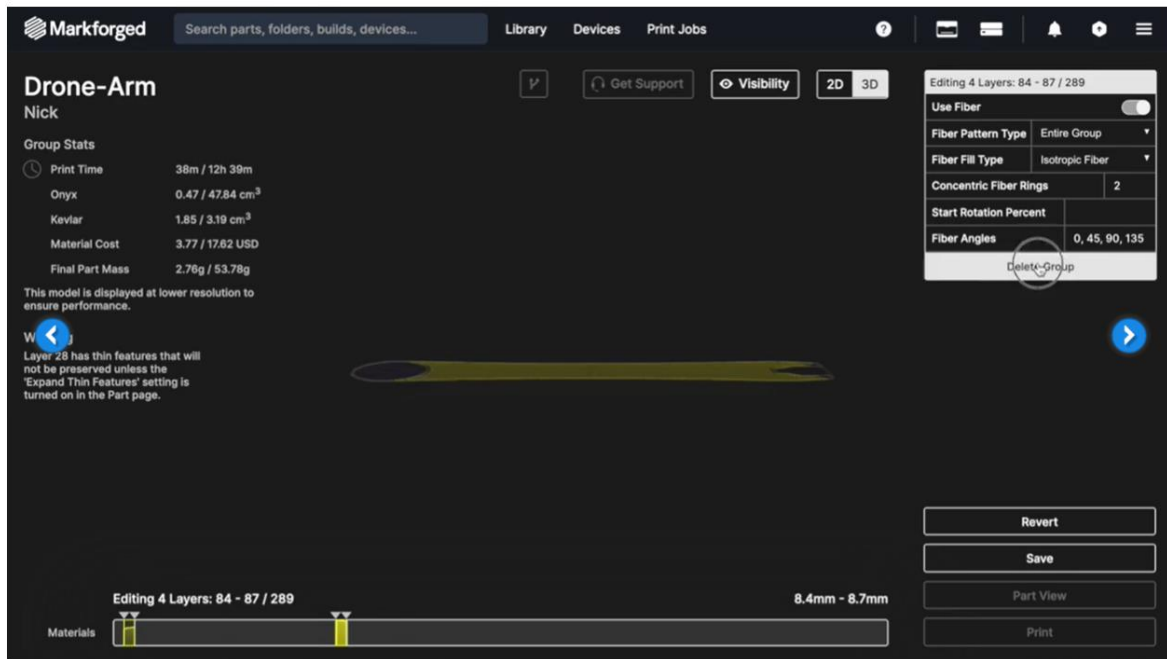


- For a default of 4 layers thick start on 84.

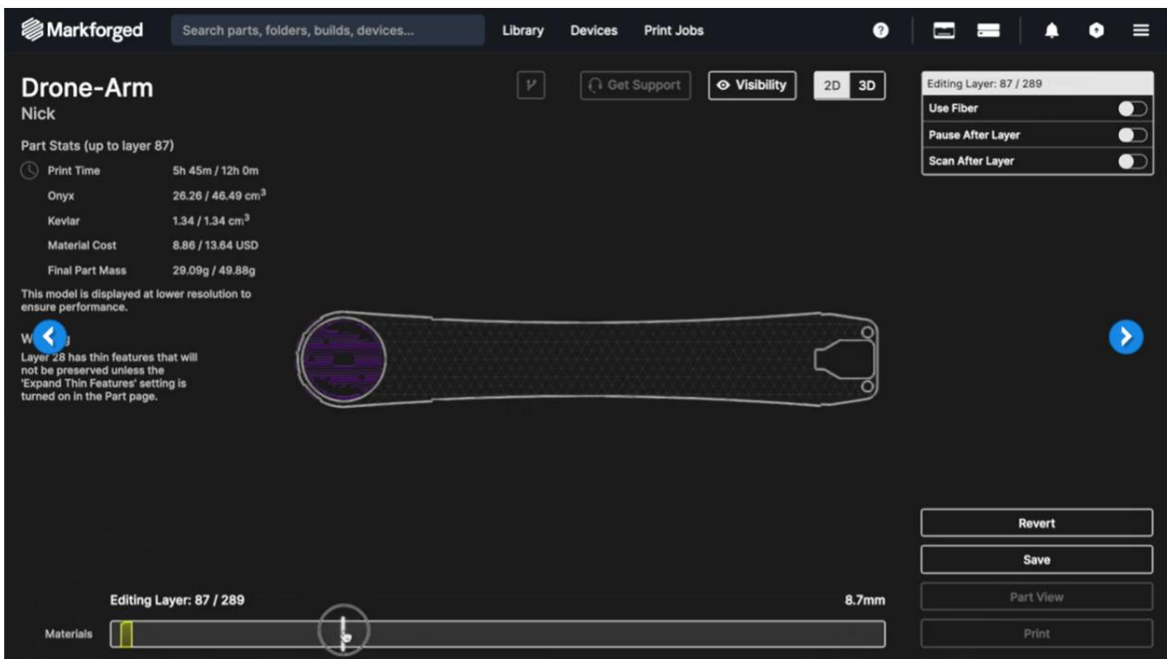


- Working with index handles is not a great strategy.
  - Tall part needs a lot of time to slice. **So instead something different.**





- To delete this: Click on bar and Delete Group.

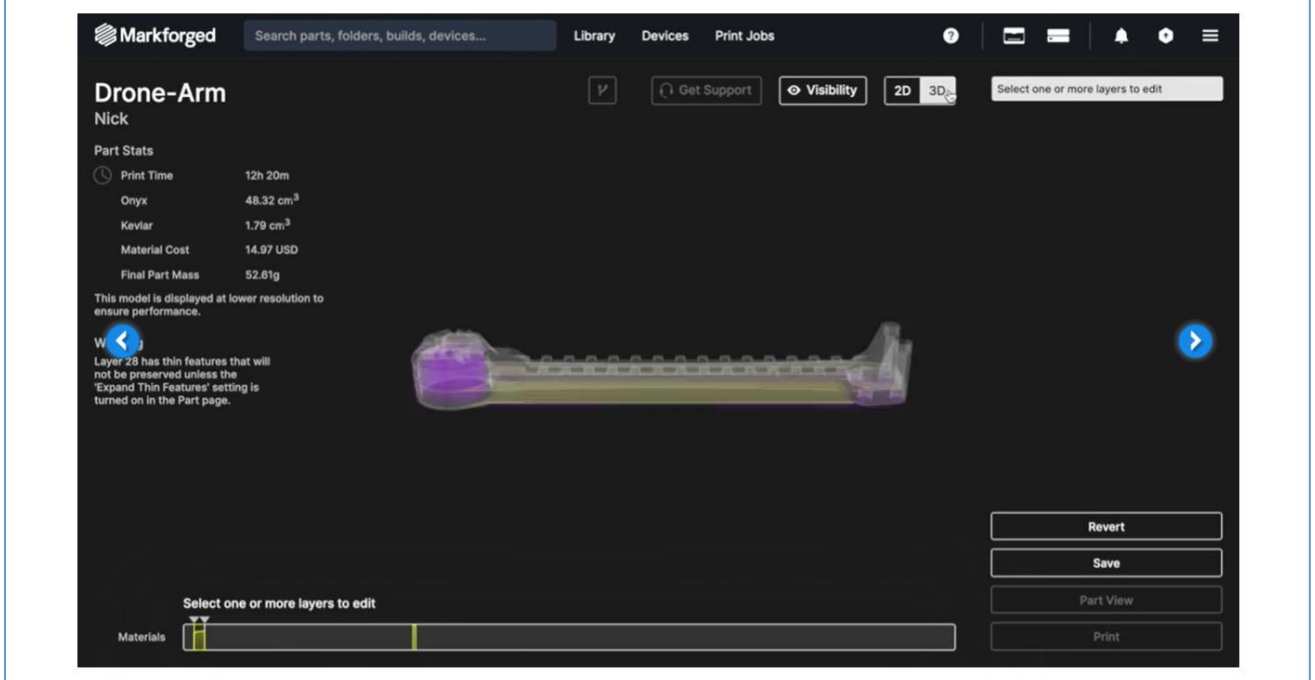


- 2D view and navigate to the layer you want

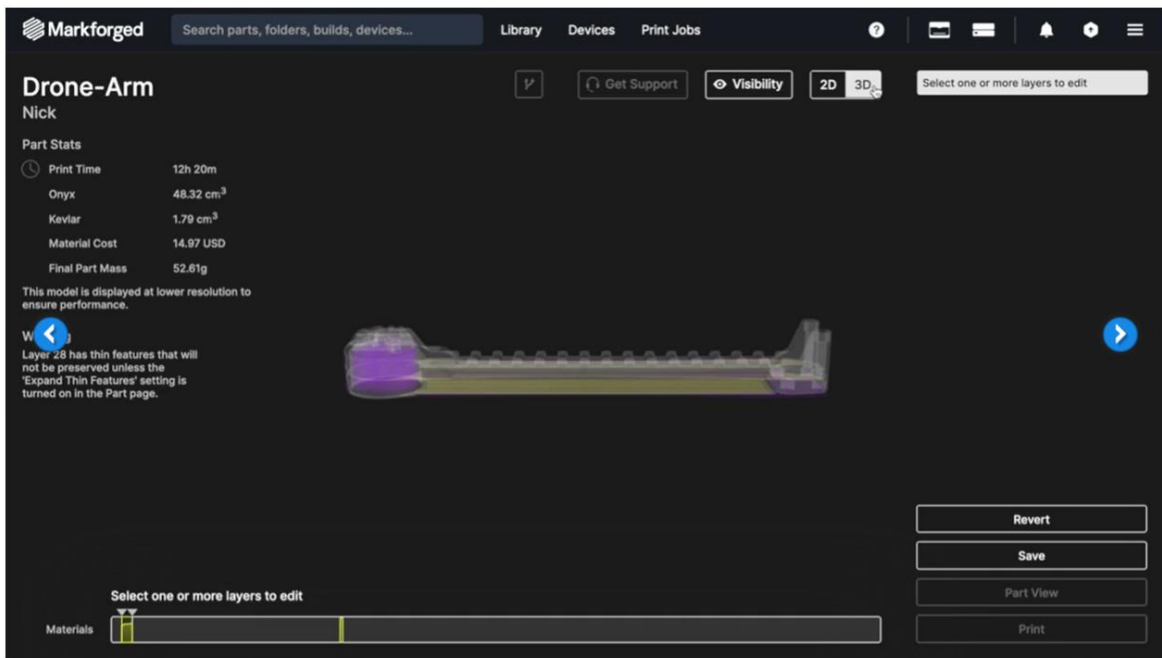


○ Use Fiber.

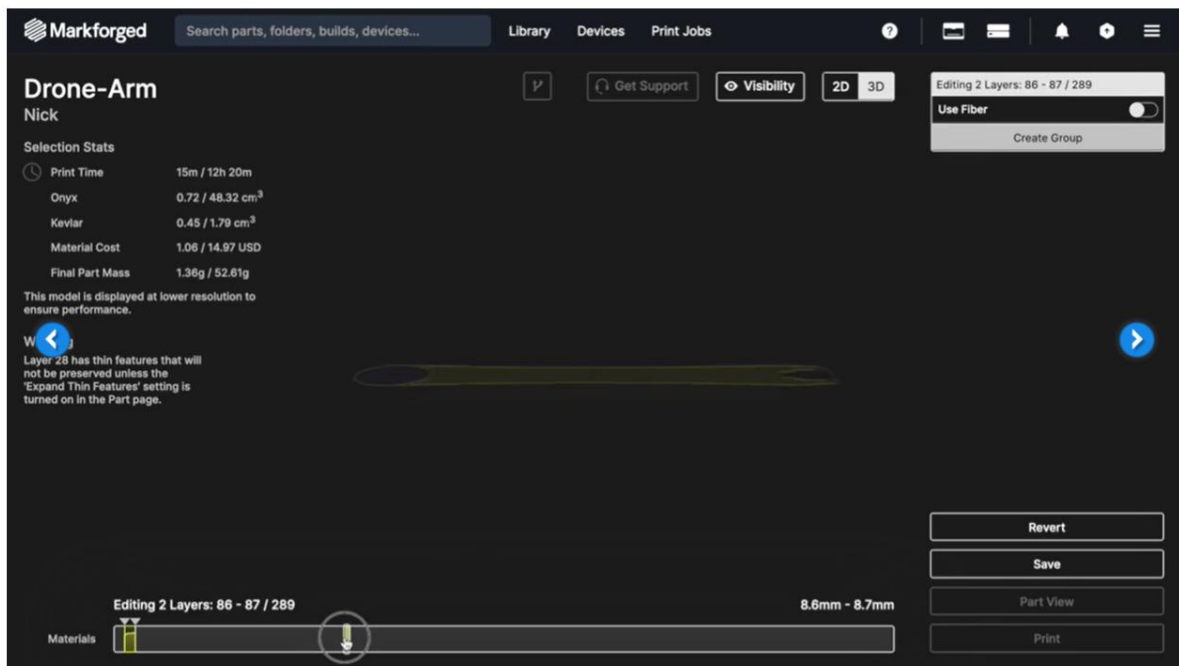




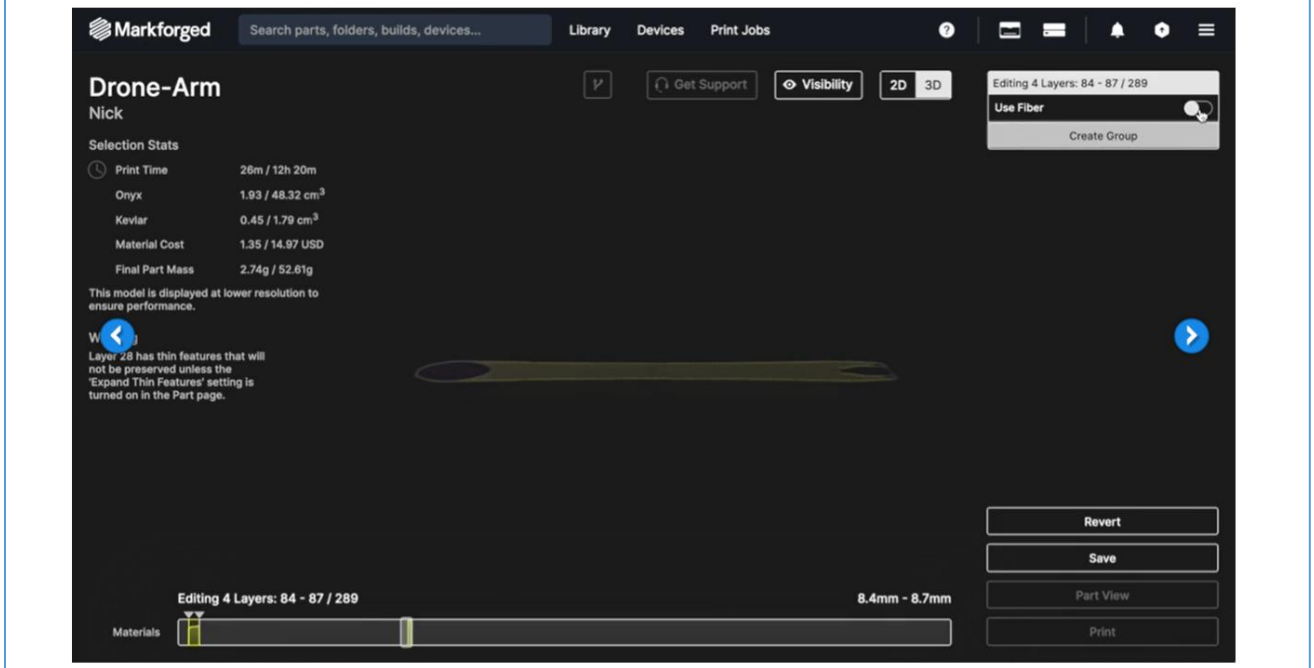
- Configure the top of the layer group > 3D.



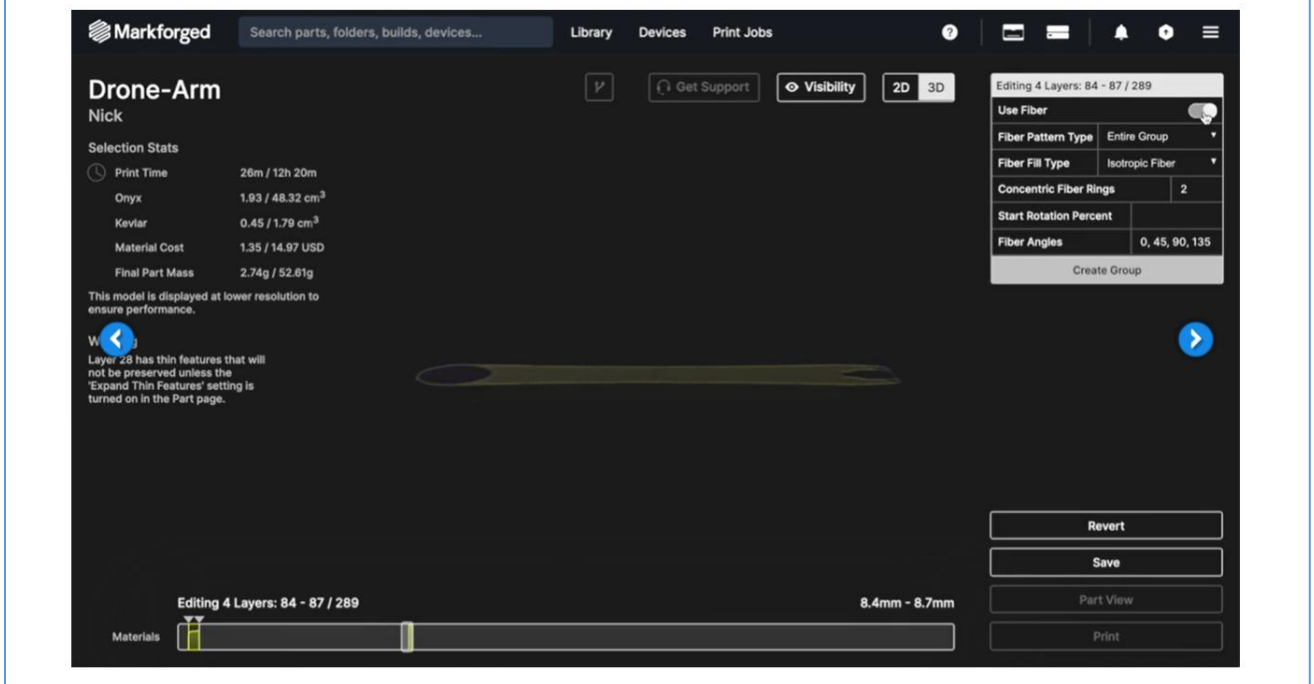
- The yellow indication is the layer we just added, at 87.
  - To use as a marker.

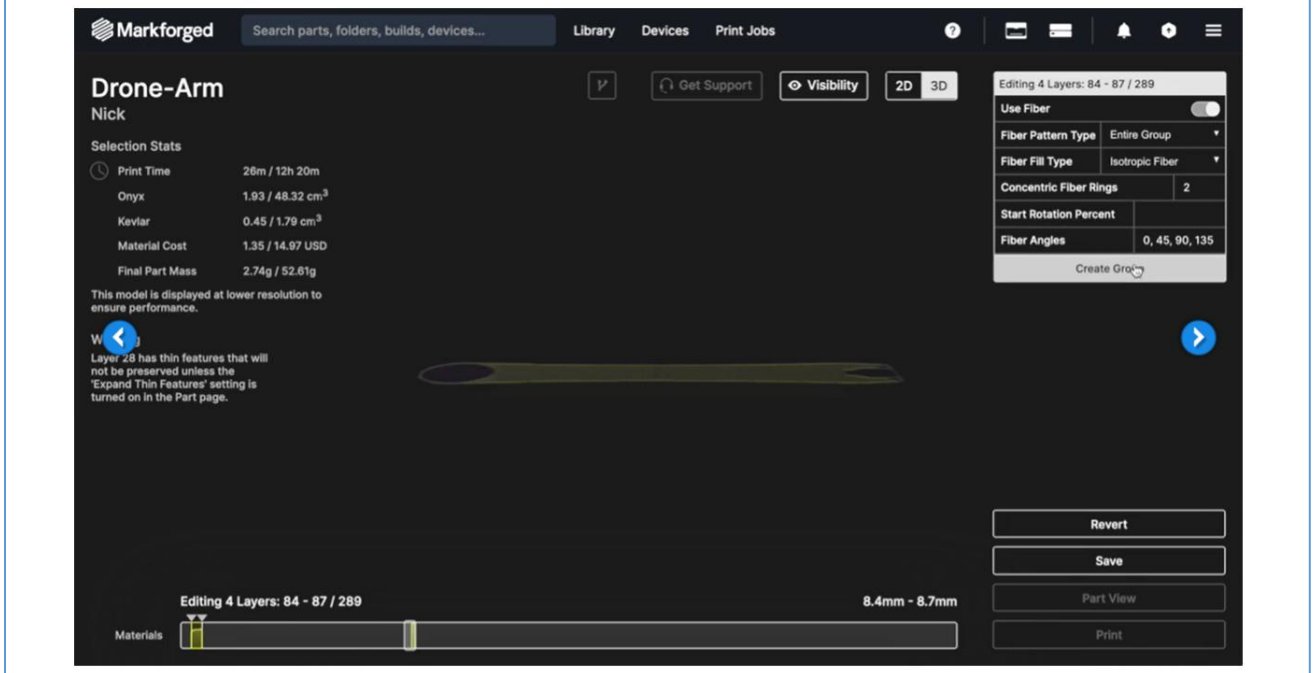


- Use as a marker for a new layer group.
  - Click and drag in layer bar.
  - And create a four layer selection.
  - This is a selection right now, not a group.

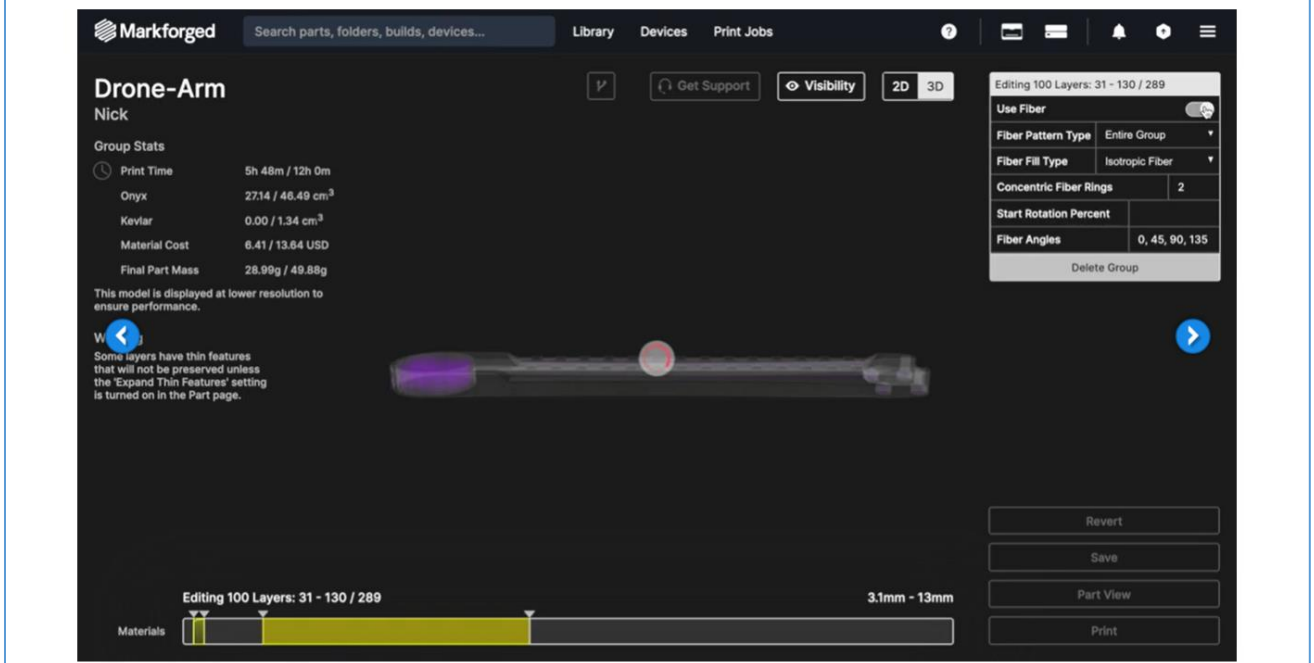


- Creating a group.



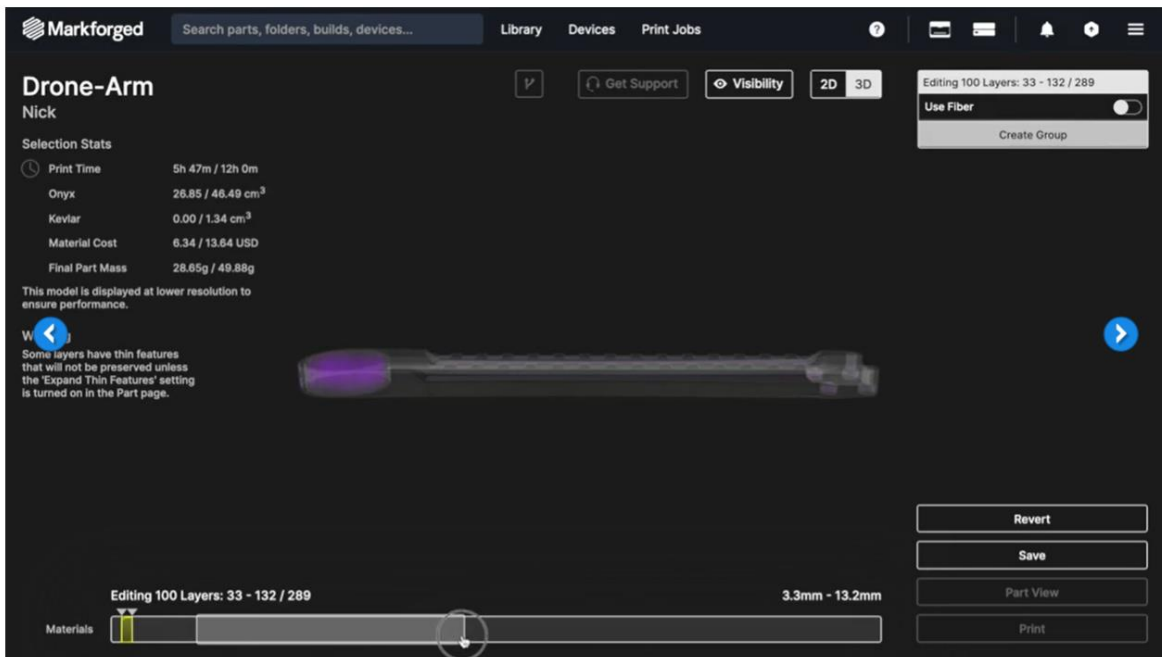


- Create Group Button.

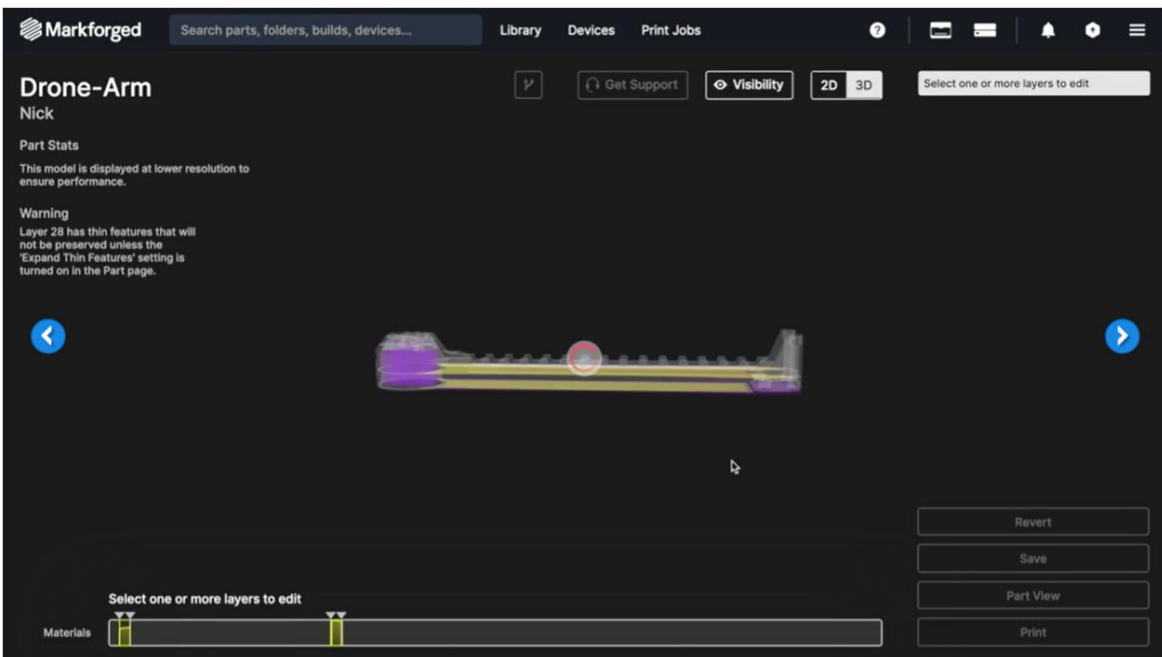


- Wrong Sequence if you want different fill type from the global default:
  - Make a layer selection.
  - Create a Group.
  - Then toggle fiber.
  - Than fill type (Concentric or Isotropic).
- Eiger will slice the entire group with the incorrect fill type, before it fill with the type you want.

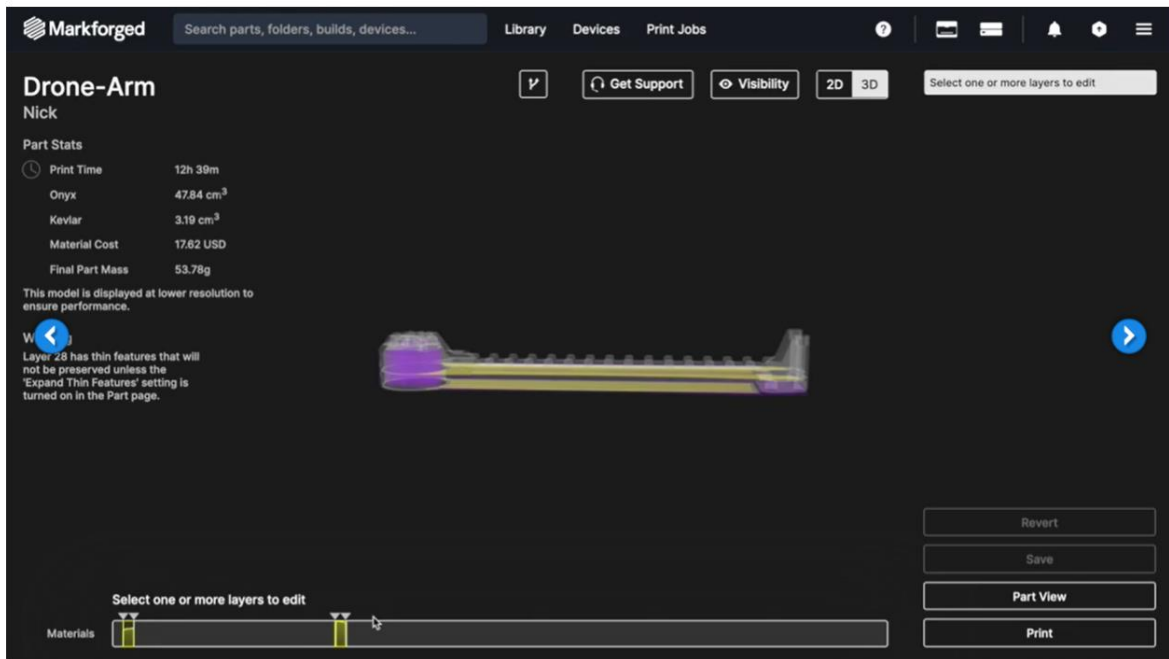




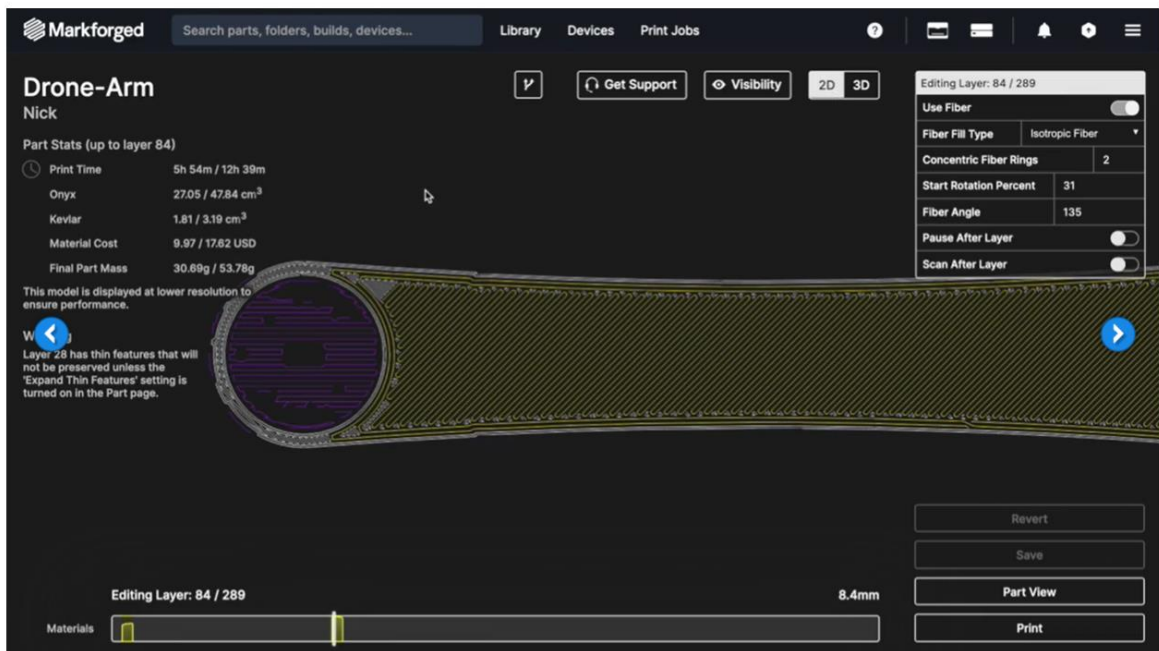
- Wright sequence:
  - Make a layer selection.
  - Toggle fiber.
  - Choose the fill type you want.
  - **ONLY THAN CREATE THE GROUP.**
- Eiger slice the group once.



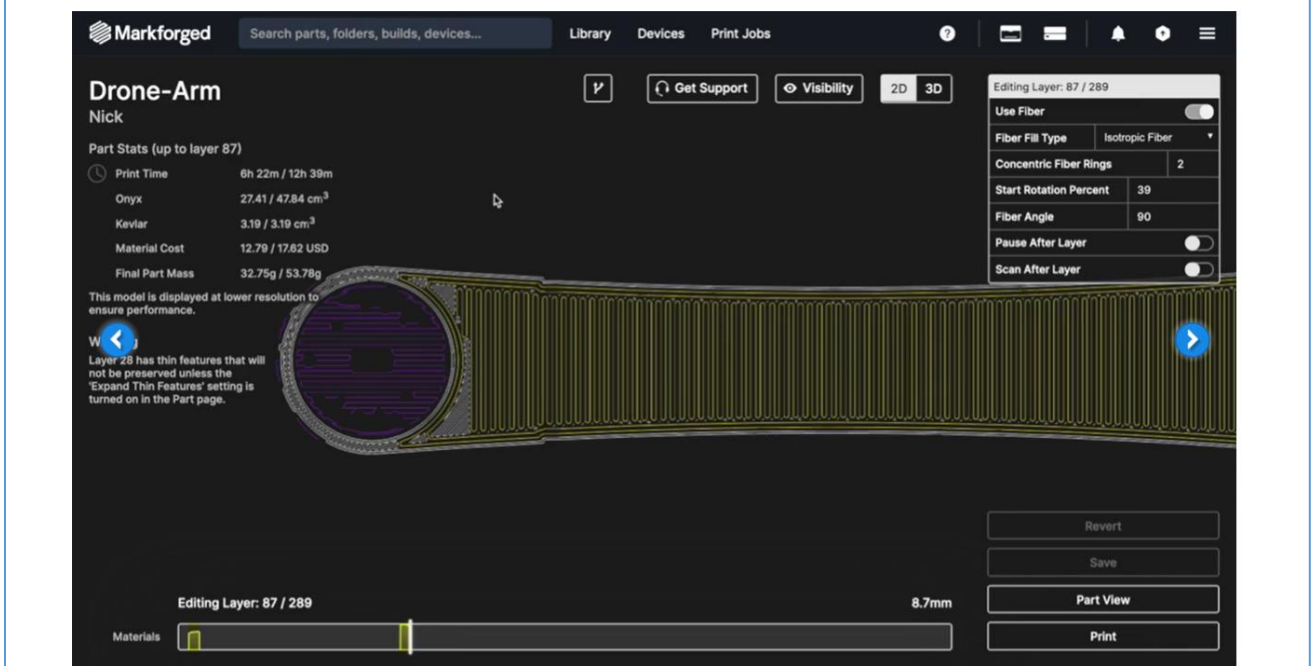
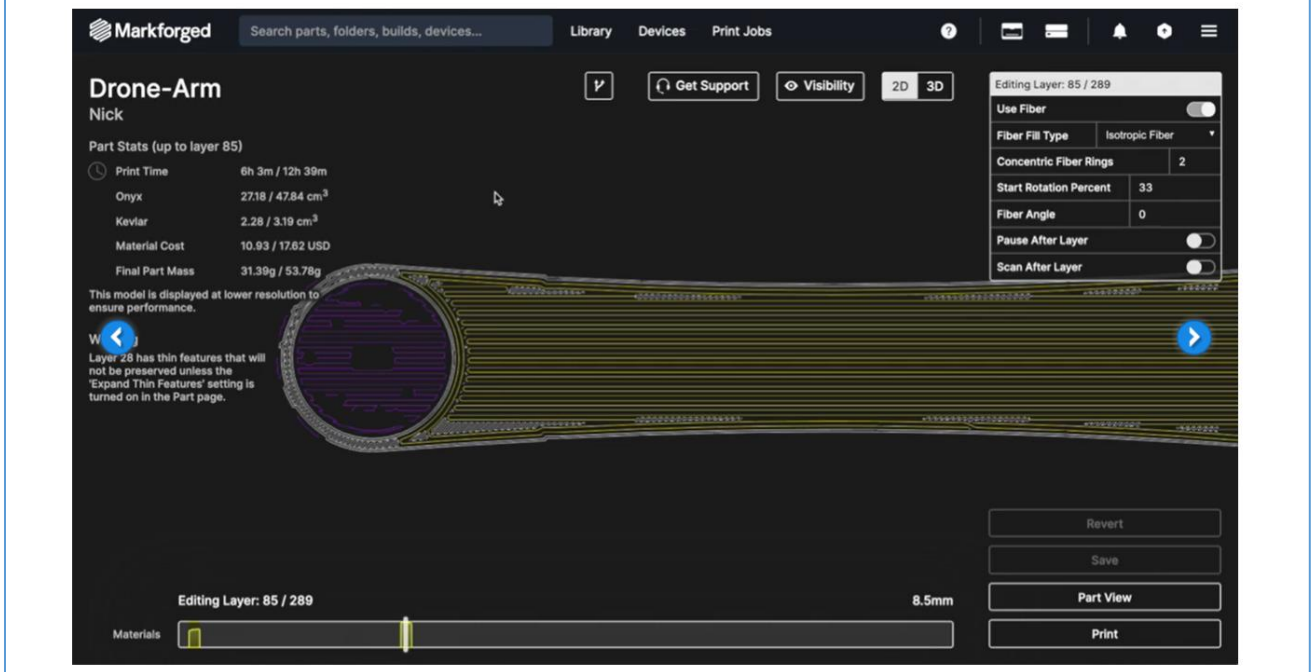
- And save your work.

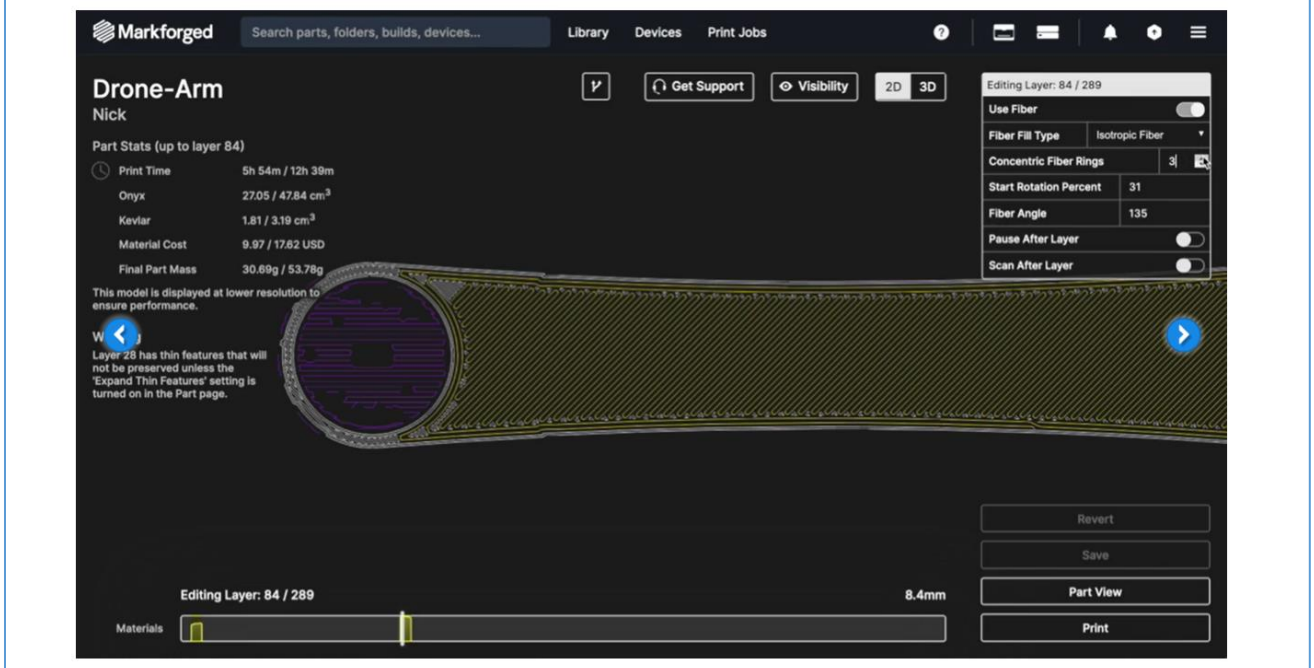
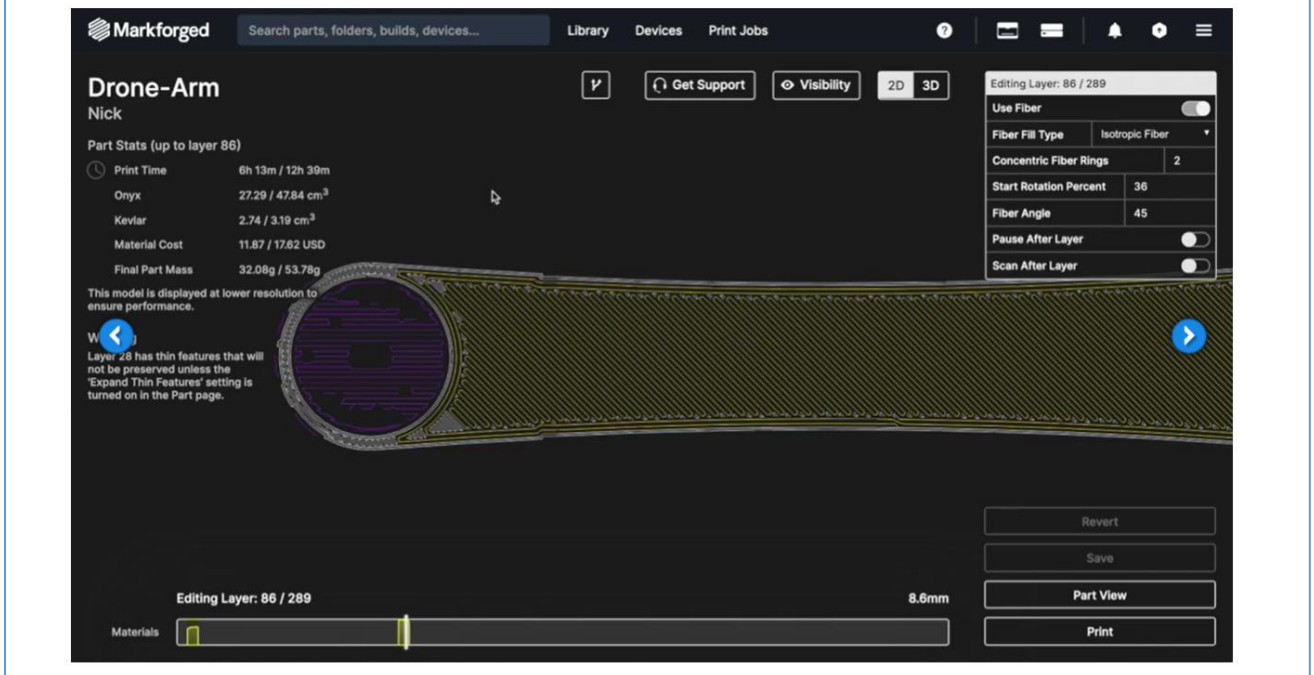


- Click on the group to select it.
  - It wasn't automatically created by Eiger.
  - Click on the upper group to select it.
  - Switch to 2D-view, that will take us to first layer in the group.

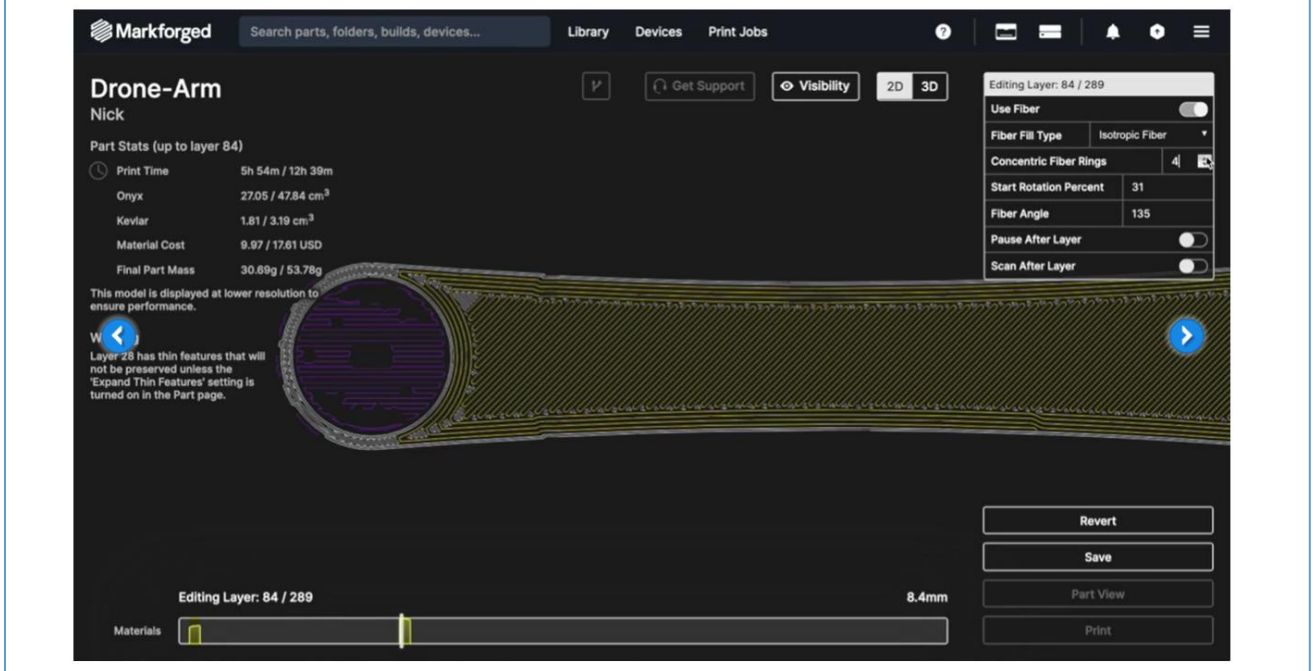


- Notice: Eiger rotates automatically the direction 45° each new layer.
  - Controlled by Fiber Angle in right box.

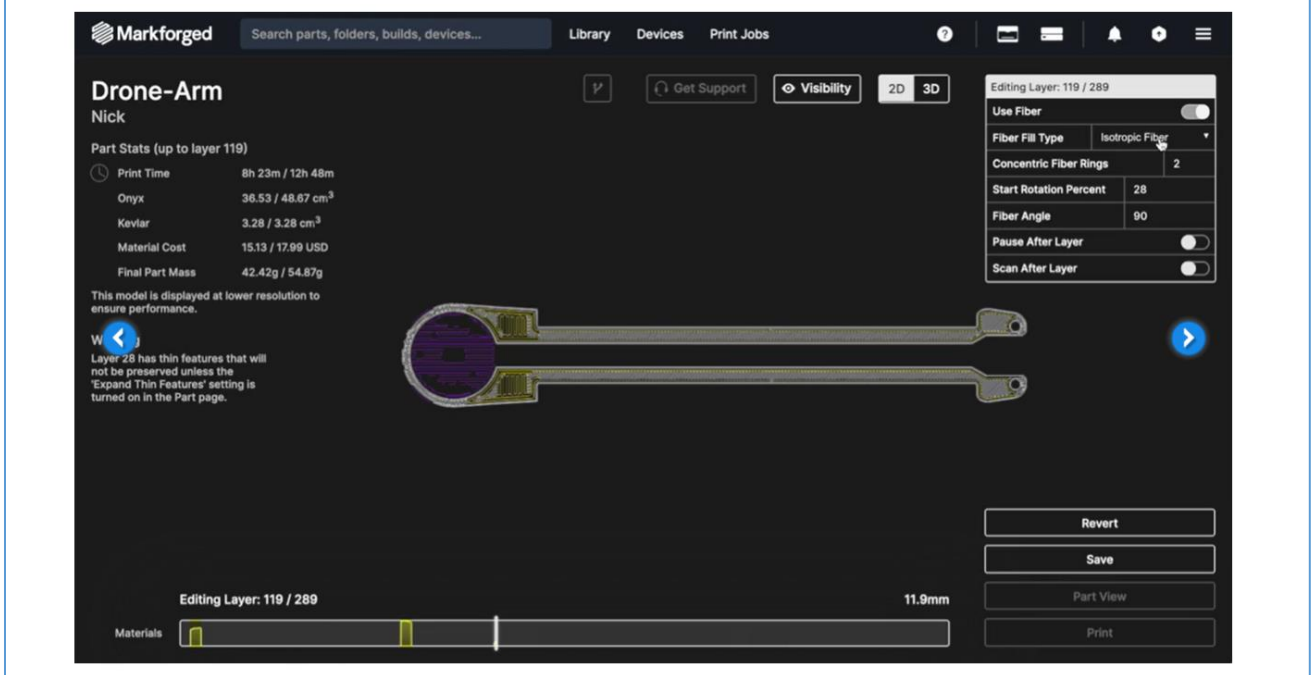




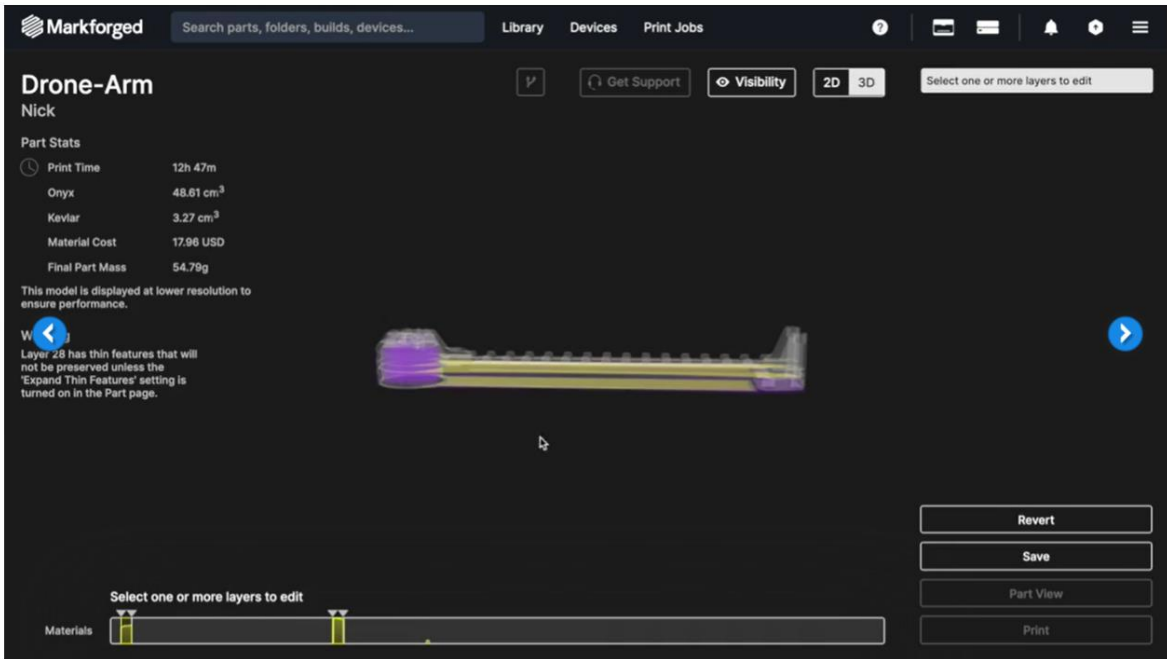
- You can also create Concentric Fiber Rings.



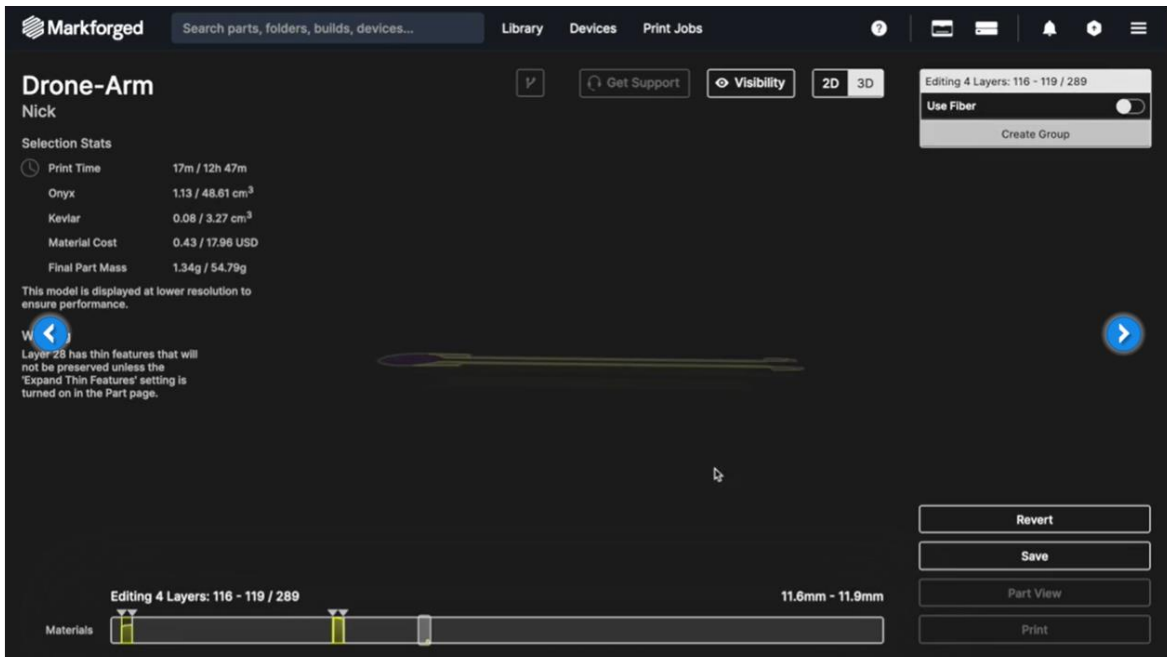
- Increasing the number of Rings.



- In these layers the reinforcement does not very much.
  - So let us change it into Concentric Fiber.

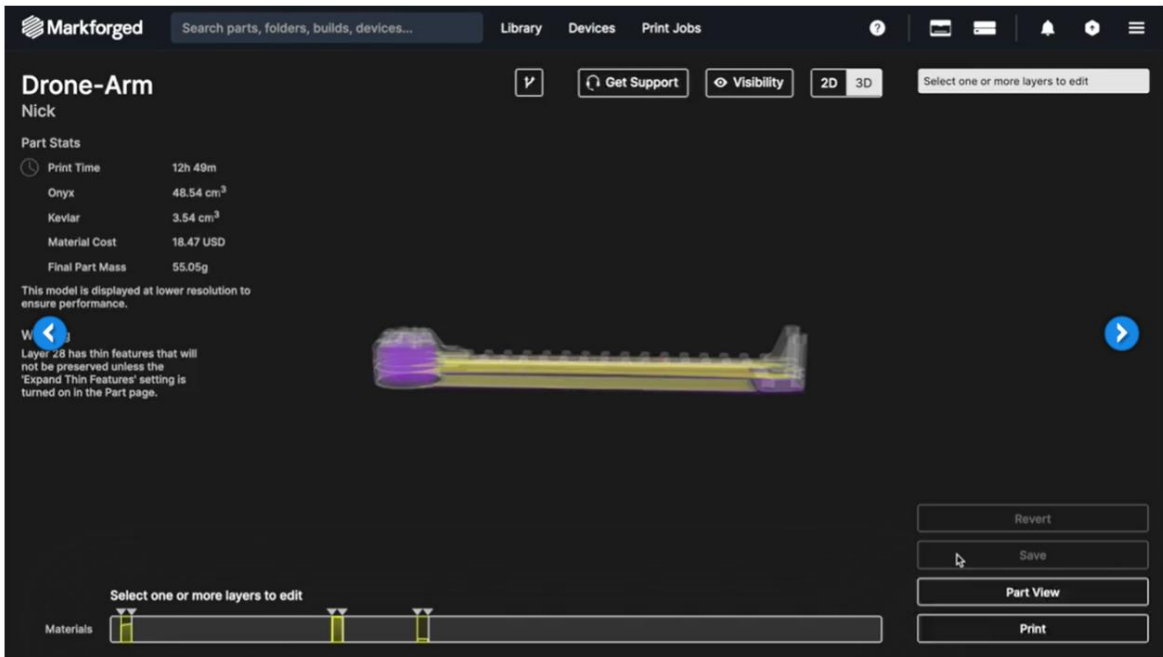


- Use the same technique:
  - 3D-view
  - Yellow Indicator as a Starting Point.



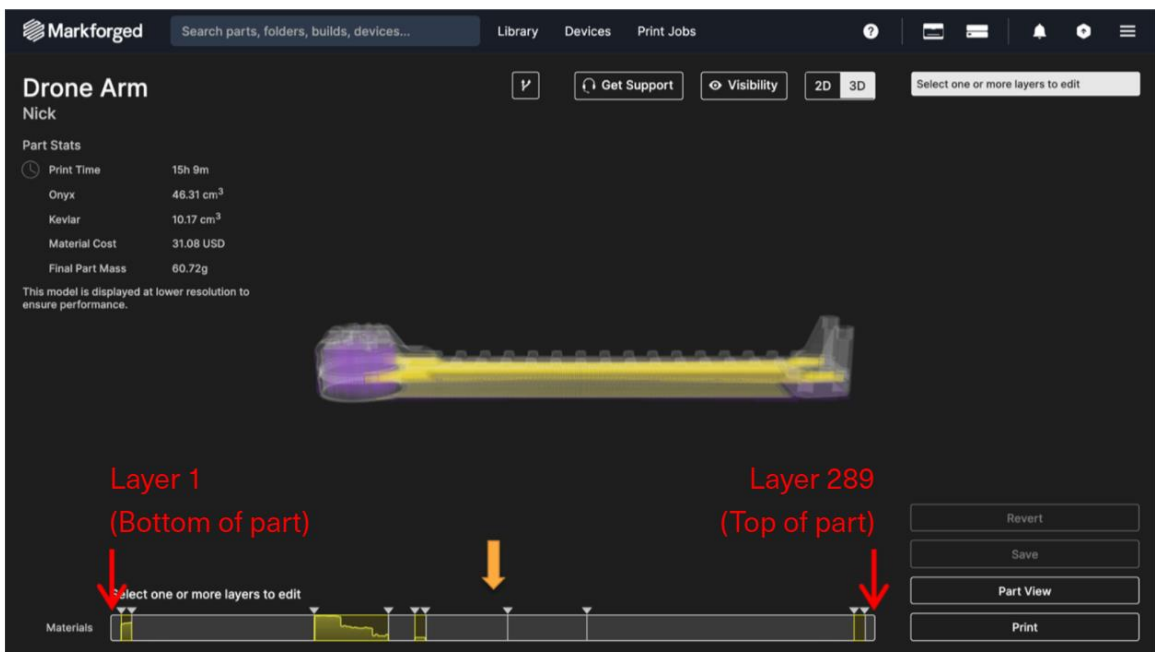
- Select the layers first.
- Toggle Fiber on.
- Choose Fill Type.
- Than Create the Group.

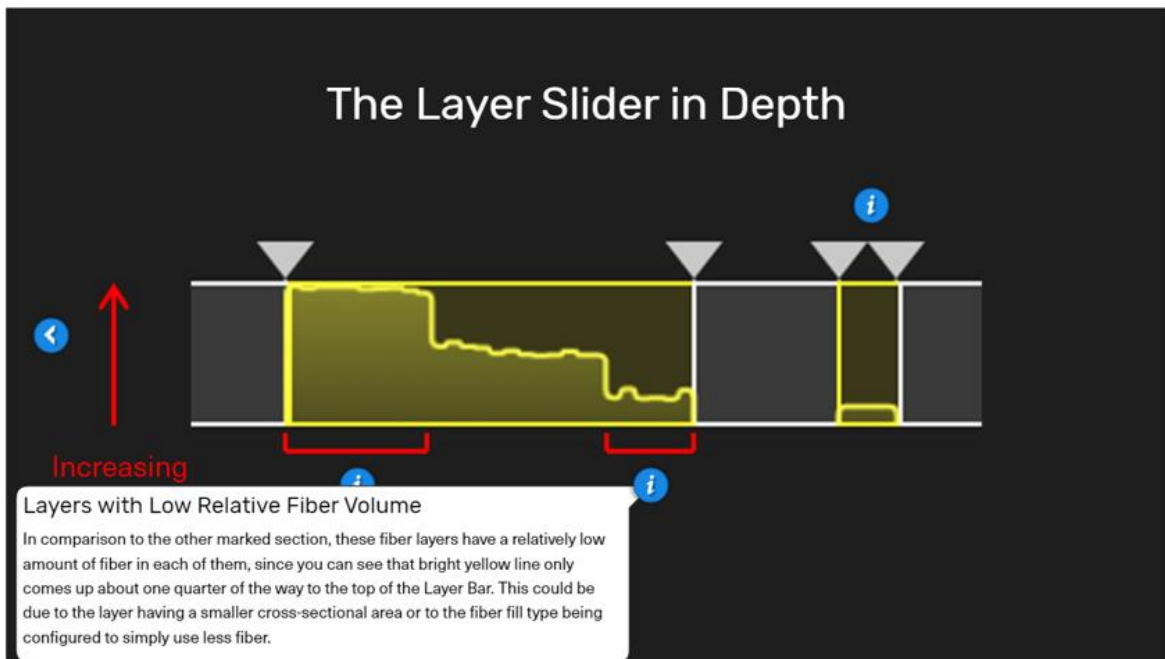
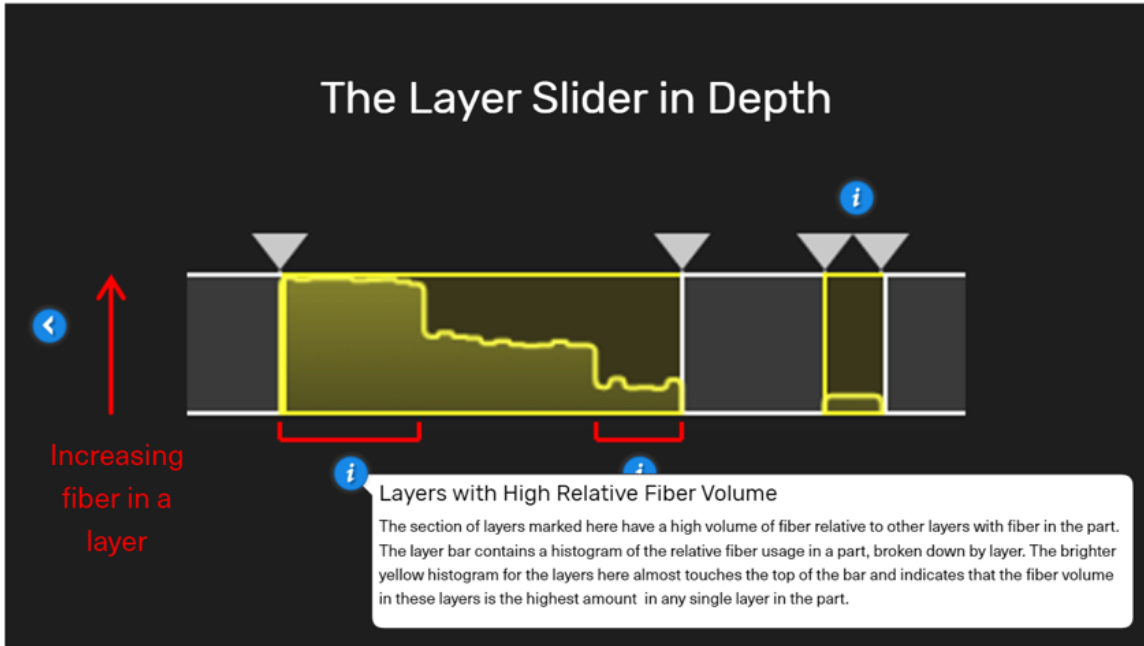




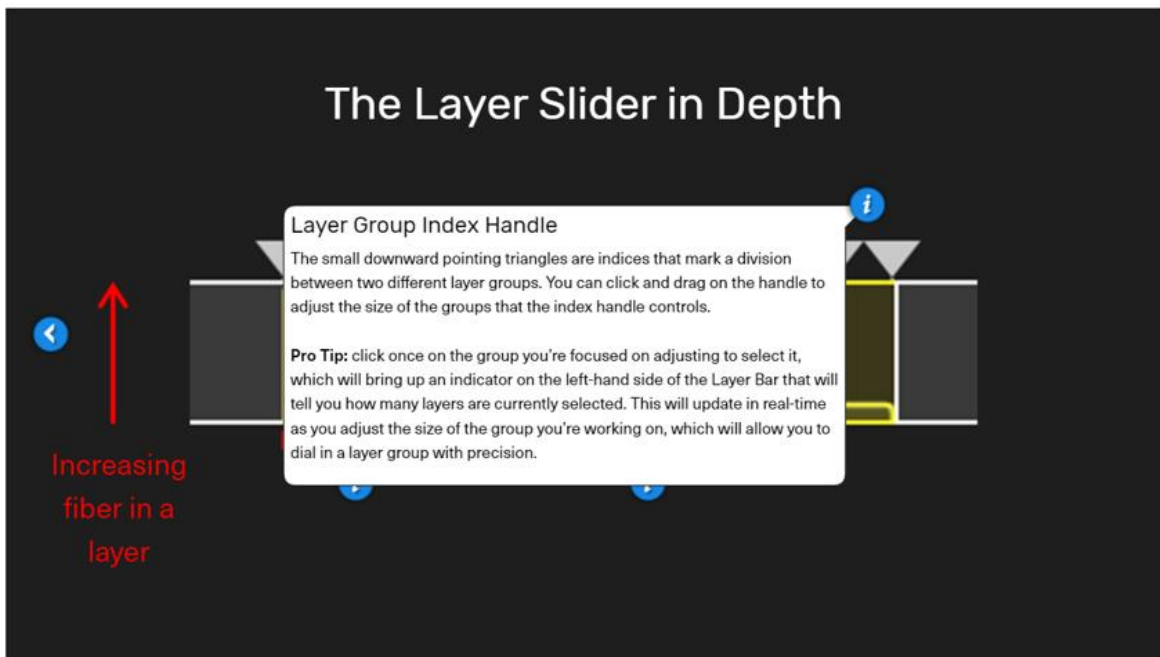
- Save your work.

- A Closer Look at The Layer Slider





## The Layer Slider in Depth



**Layer Group Index Handle**

The small downward pointing triangles are indices that mark a division between two different layer groups. You can click and drag on the handle to adjust the size of the groups that the index handle controls.

**Pro Tip:** click once on the group you're focused on adjusting to select it, which will bring up an indicator on the left-hand side of the Layer Bar that will tell you how many layers are currently selected. This will update in real-time as you adjust the size of the group you're working on, which will allow you to dial in a layer group with precision.

Increasing fiber in a layer

## Review: Print Orientation Drives Four Things



**Supports**



**Z-axis  
Direction**



**Horizontal  
Features**



**Fiber  
layout**

- **Review: Print Orientation Drives Four Things**



## Module Review

- **Module Review**

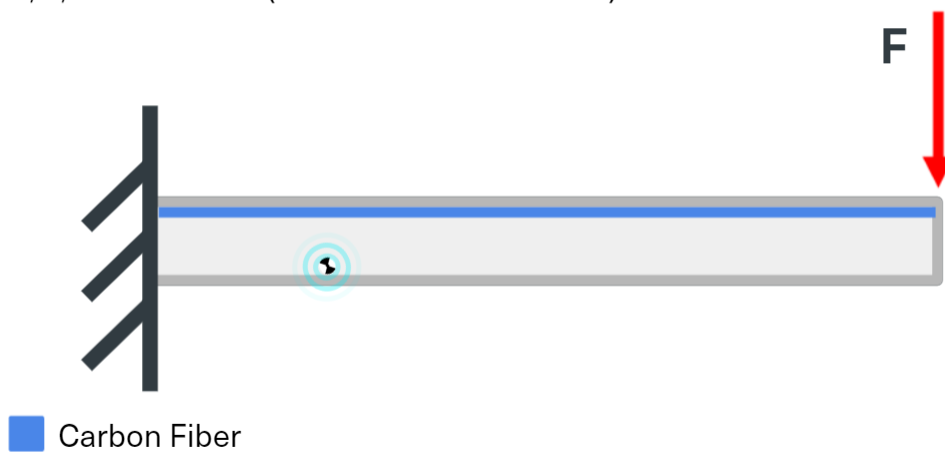
A single filament of composite fiber is by itself strongest in:

- Compression
- Bending
- Tension
- Shear

Mark all of the following considerations that can be significantly influenced by changing the print orientation of a part.

- Plastic FFF material selection
- Which features are printed as 'horizontal features'
- The STL file size of the part
- Where in the part you can lay fiber
- The presence and amount of support structures

Click on the area of this beam where you should add fiber, in order to complete the sandwich panel construction, and which would also be effective reinforcement if the force,  $F$ , was reversed (rotated 180° in direction).



True/False: A sandwich panel is an extremely lightweight and materially-efficient way to produce a high-strength and high-stiffness structure from multiple materials.

True

False

### Results

Your Score: 100% (40 points)

Passing Score: 80% (32 points)

### Result:



Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)



## C2.3 – Design for FFF and CFF Part 1

☰ C2.3 - Design for FFF+CFF Part 1

RESOURCES



- **Design for FFF and CFF Part 1**

☰ C2.3 - Design for FFF+CFF Part 1

## Module Overview

Guess the Manufacturing Process

Markforged DfAM Framework Review

Identifying Critical Functional Requirements

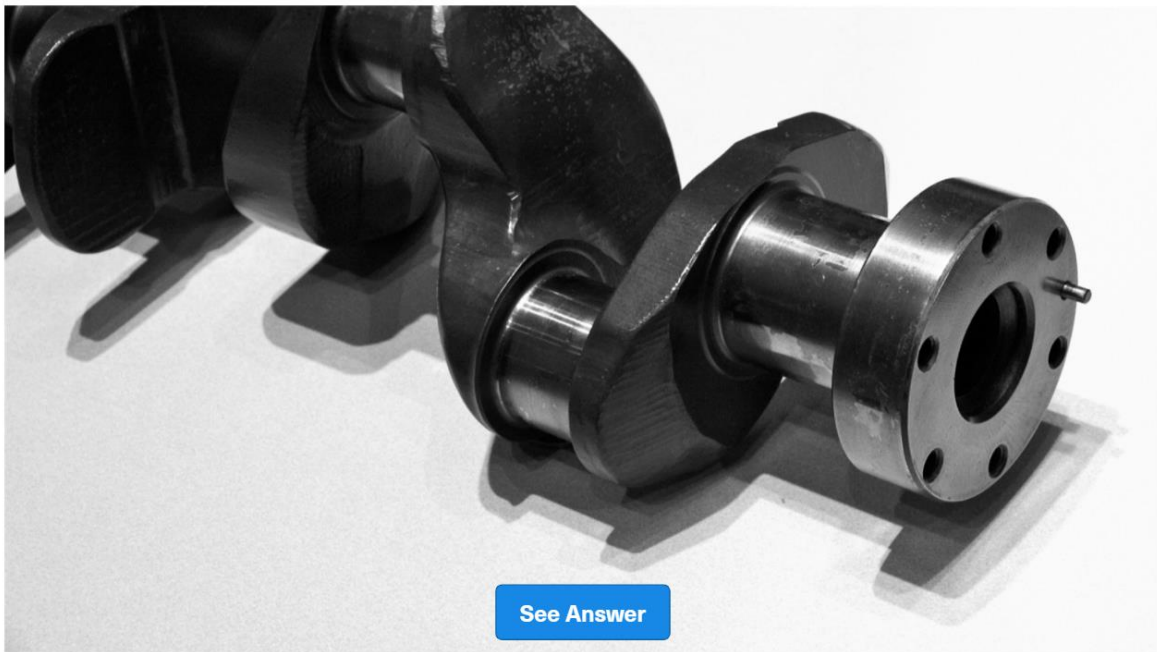


- **Module Overview**



What manufacturing process produced the following parts?

- **What's the Manufacturing Process?**



[See Answer](#)

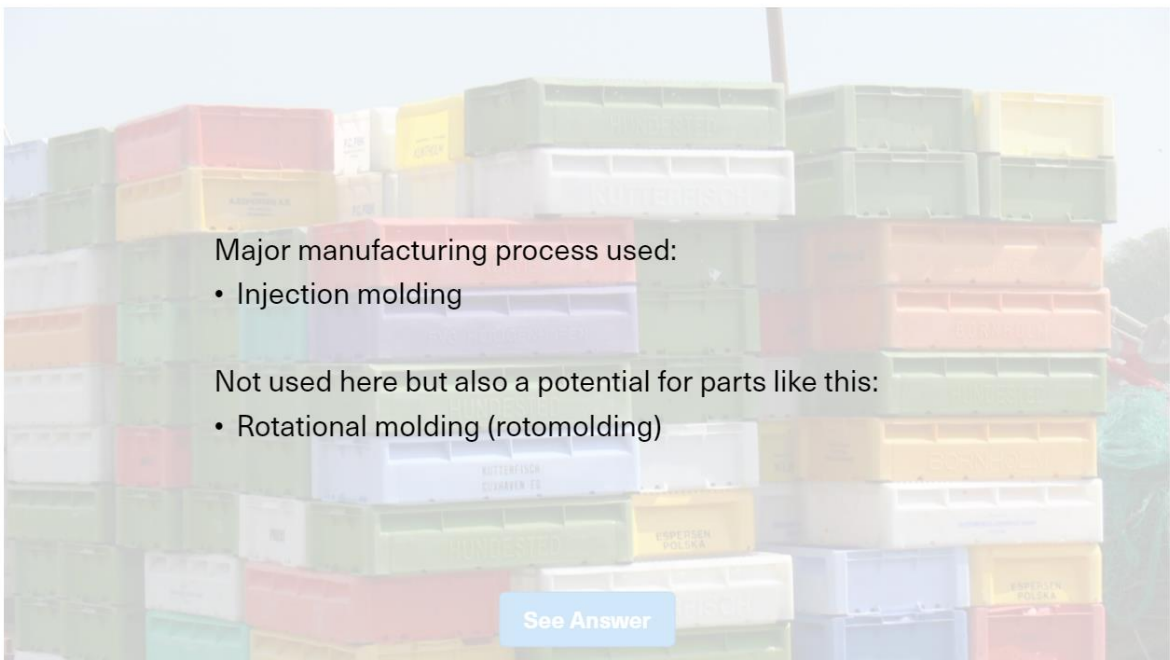
- **Example 1**



Major manufacturing processes used could include:

- Casting
- Forging
- Grinding/Polishing
- Machining

See Answer



Major manufacturing process used:

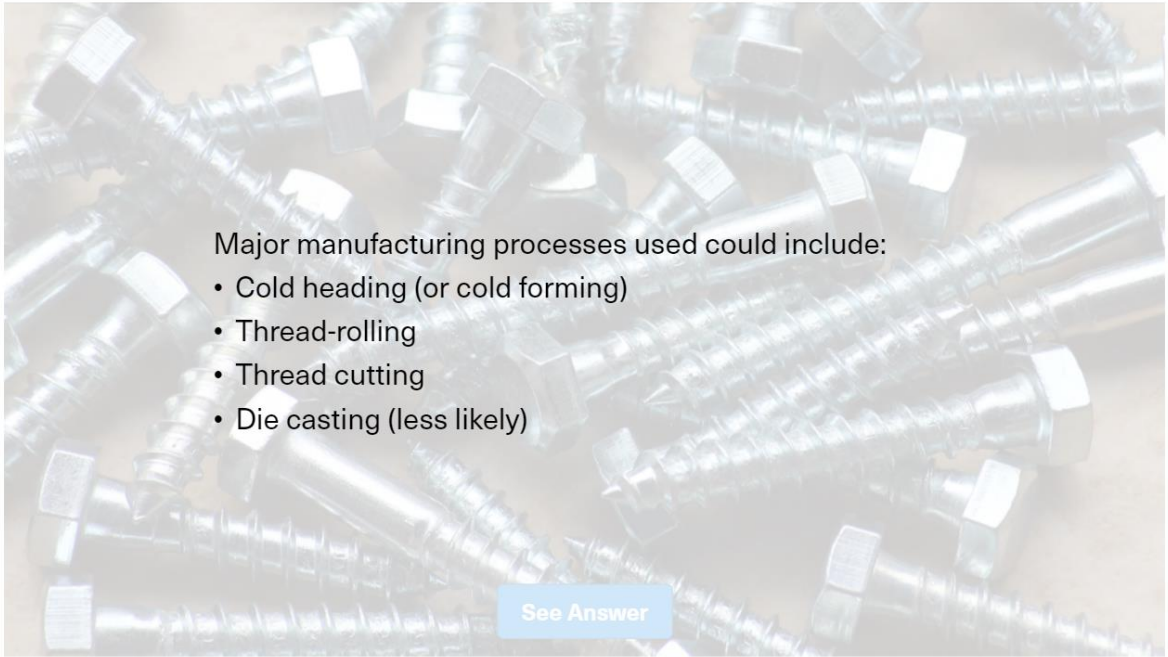
- Injection molding

Not used here but also a potential for parts like this:

- Rotational molding (rotomolding)

See Answer

- **Example 2**

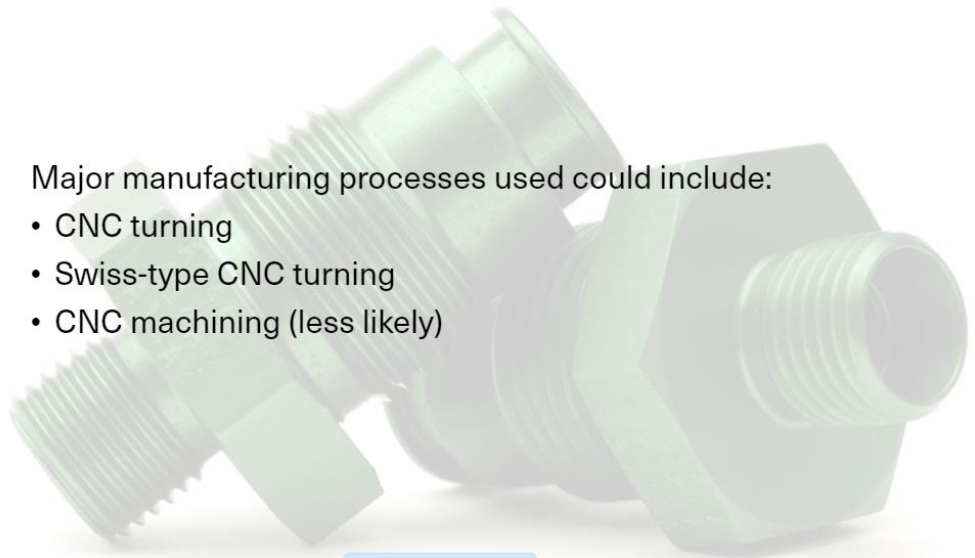


Major manufacturing processes used could include:

- Cold heading (or cold forming)
- Thread-rolling
- Thread cutting
- Die casting (less likely)

[See Answer](#)

• **Example 3**



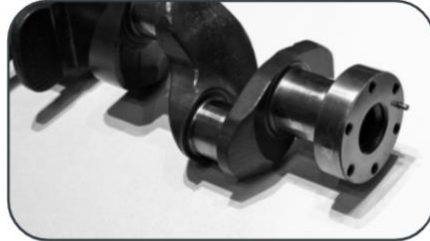
Major manufacturing processes used could include:

- CNC turning
- Swiss-type CNC turning
- CNC machining (less likely)

[See Answer](#)

• **Example 4**

What do these parts all have in common?



- **Recap: What Do These Parts in Common?**

Answer: They were all designed for a specific manufacturing process

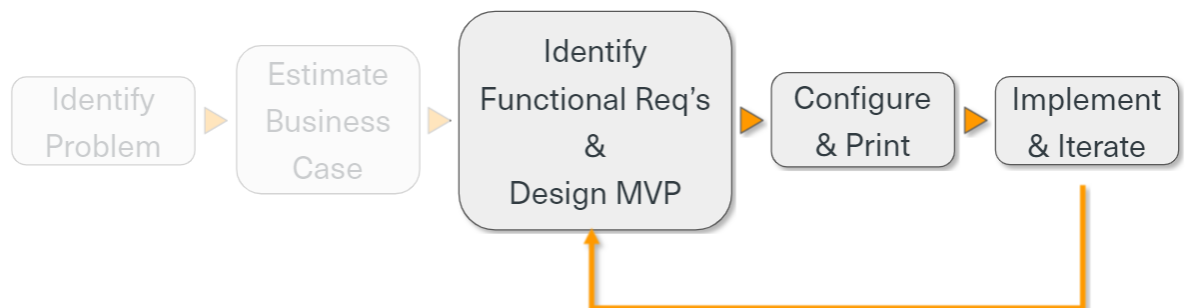


- **The Answer**



- ◀ The best 3D printed parts are designed for 3D printing

## Review: Design for AM Framework



- **Review: Design for AM Framework**

- Additive Manufacturing
- MVP = Minimal Viable Product (V=levensvatbaar)
- Iterate = herhalen



Defined Problem -  - Functional MVP


- **Defined Problem to Functional MVP**

## Problem → MVP Workflow

1. Identify **core functionality**
2. First pass **design/block CAD**
3. **Revise design** to meet core functionality
4. Import into **Eiger**
5. First pass **print settings** and material **selection**
6. **Print and test**

- **Problem → MVP Checklist**

☰ C2.3 - Design for FFF+CFF Part 1



## Identifying Core Functionalities

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- **Identifying Core Functionalities**

☰ C2.3 - Design for FFF+CFF Part 1

## Why We Identify Core Functionalities

- Understand minimum functional requirements of part
- Discover unexpected potential challenges early in process
- Inform material selection, reinforcement strategy and print orientation

Markforged University

- **Why We Identify Core Functionalities**

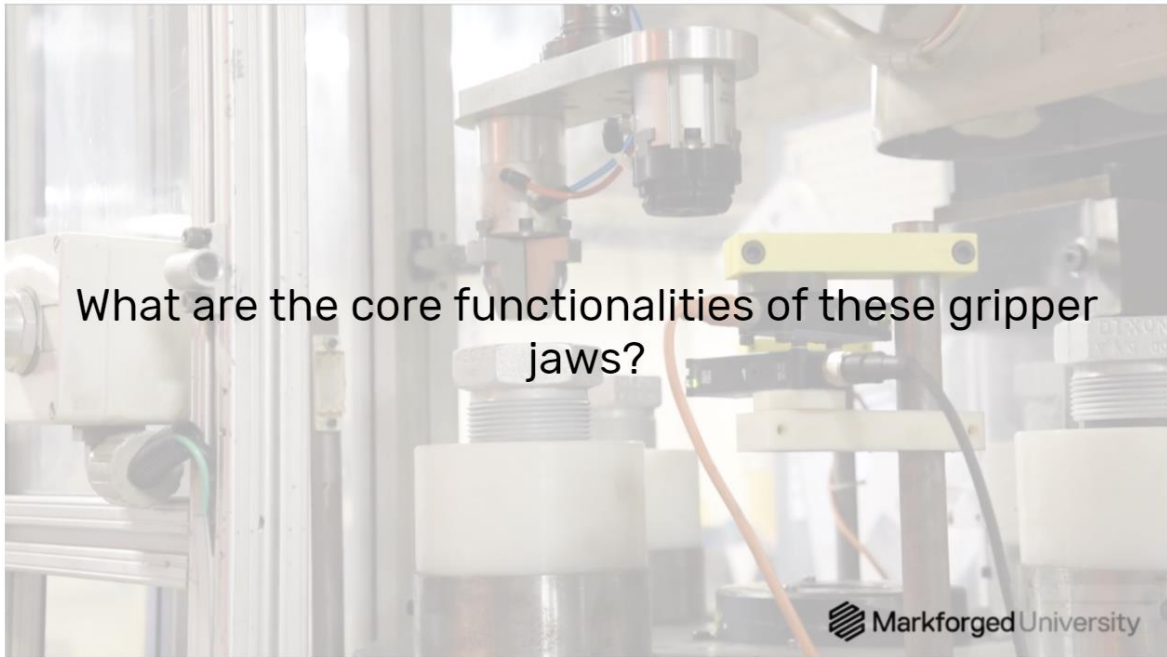
## Scenario 1: EOAT in an Automated Work Cell

- **Scenario 1: Automation Cell**
  - EOAT = End of arm tooling

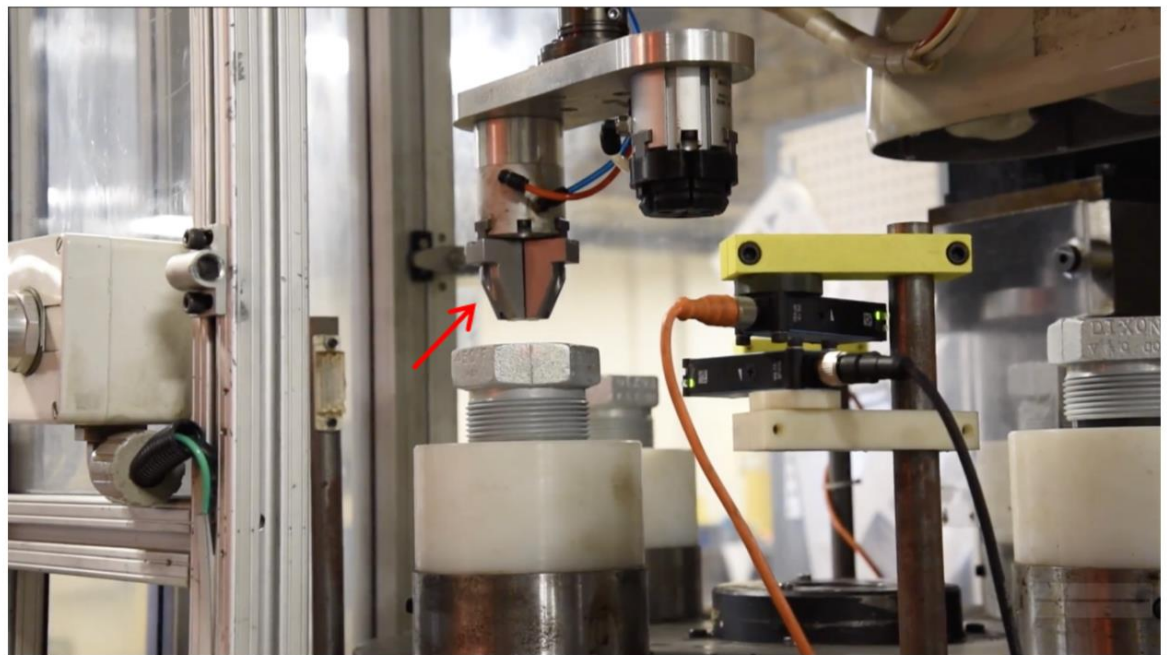








- **S1: What Are the Core Functionalities?**



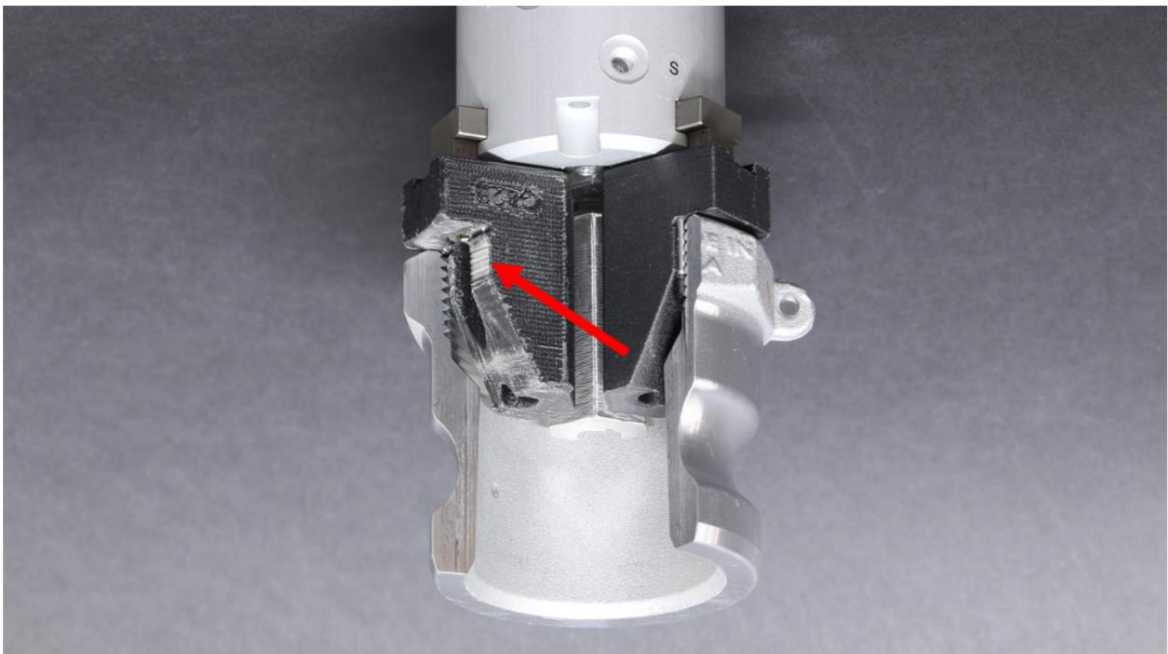


## Gripper Jaw Core Functionality

- Maintain stiffness (minimal deflection) under gripping load
- Grip coupling securely and release cleanly
- Withstand gripping force of 80 psi shop air-powered gripper
- Resist abrasion when gripping on the threaded ID of the product
- Avoid damaging the product (the casting)
- Preventative maintenance (PM)/replacement schedule of 1-2 years

- **Gripper Jaw Core Functionality**

- Deflection = doorbuiging.
- Abrasion = slijtage.



- **To be continued....**

- Lot of wear and tear on onyx surface.

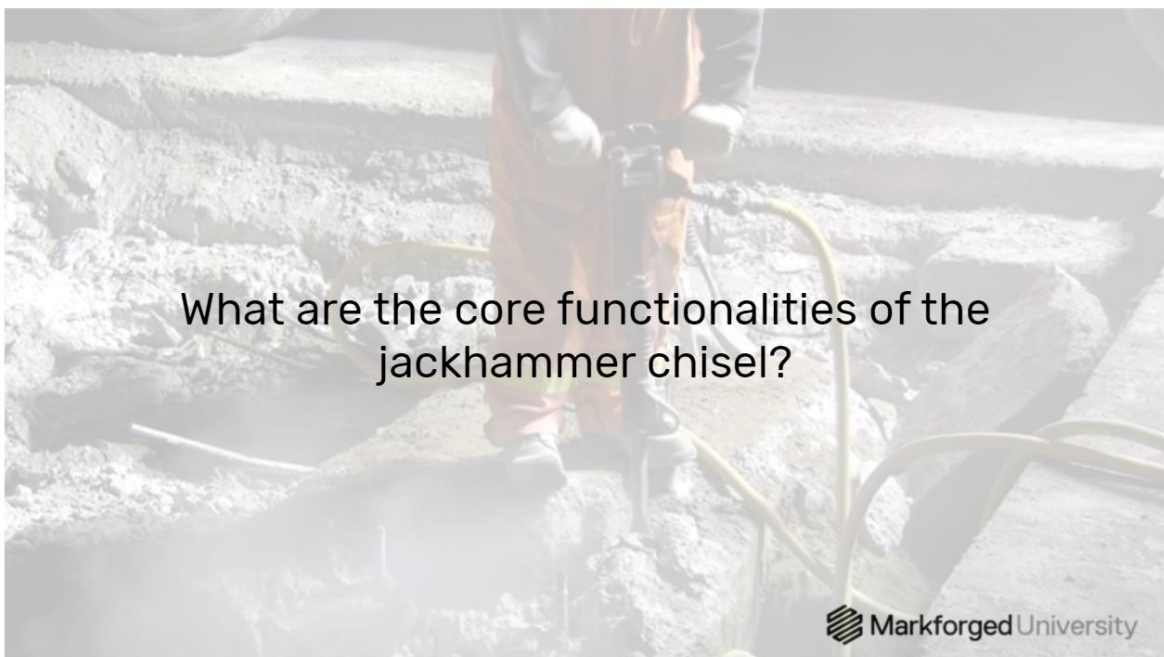
## Core Functions: Part Interactions

- Withstand contact forces
- Resist abrasive wear
- Distribute bolt forces

- **Core Functions: Part Interactions**

## Scenario 2: Jackhammer Chisel

- **Scenario 2: Jackhammer Chisel**



- **What Are The Core Functionalities?**



## Jackhammer Chisel Core Functionality

- Transmit high axial cyclic impact forces along chisel
- Resist bending force when operator performs prying motion
- Avoid deforming or shattering under load
- High wear resistance against concrete/pavement
- Resist corrosion in outdoor environments

- **Jackhammer Chisel Core Functionality**



## Core Functions: Loading Conditions

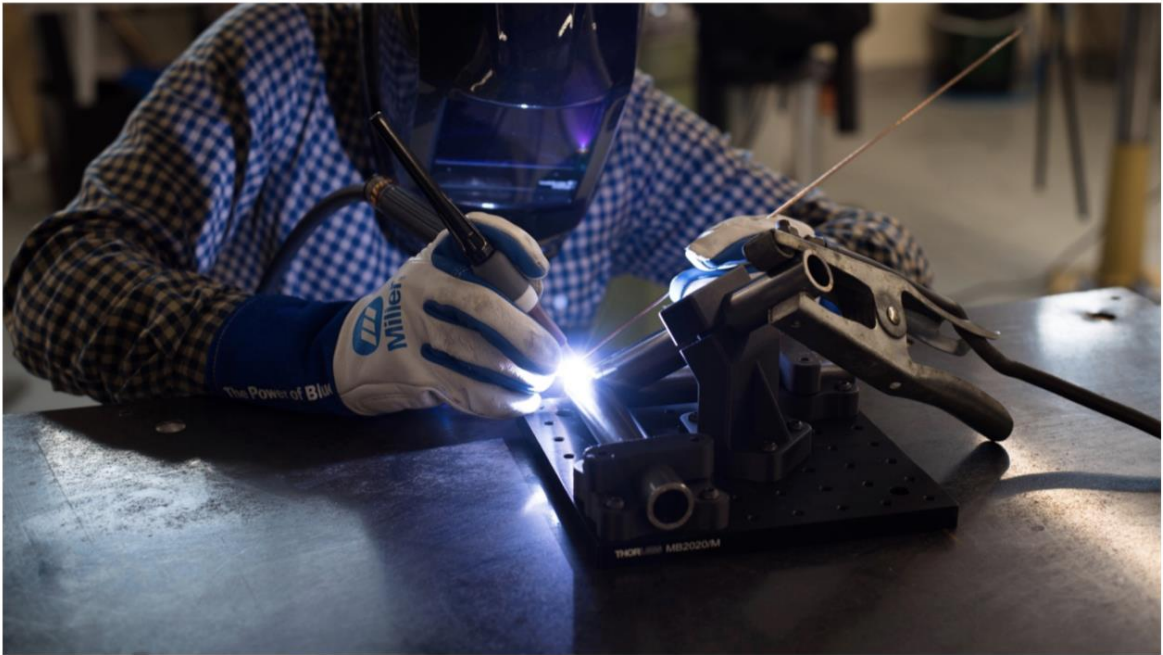
- Type (point load, distributed, torque)
- Direction
- Magnitude
- Frequency
- Duration (impact, static)

- **Core Functions: Loading Conditions**

- Torque = Koppel. Magnitude = Grootte. Duration = looptijd.



- **Scenario 3: Welding Fixture**



- **S3: What Are The Core Functionalities?**



## Welding Fixture Core Functionality

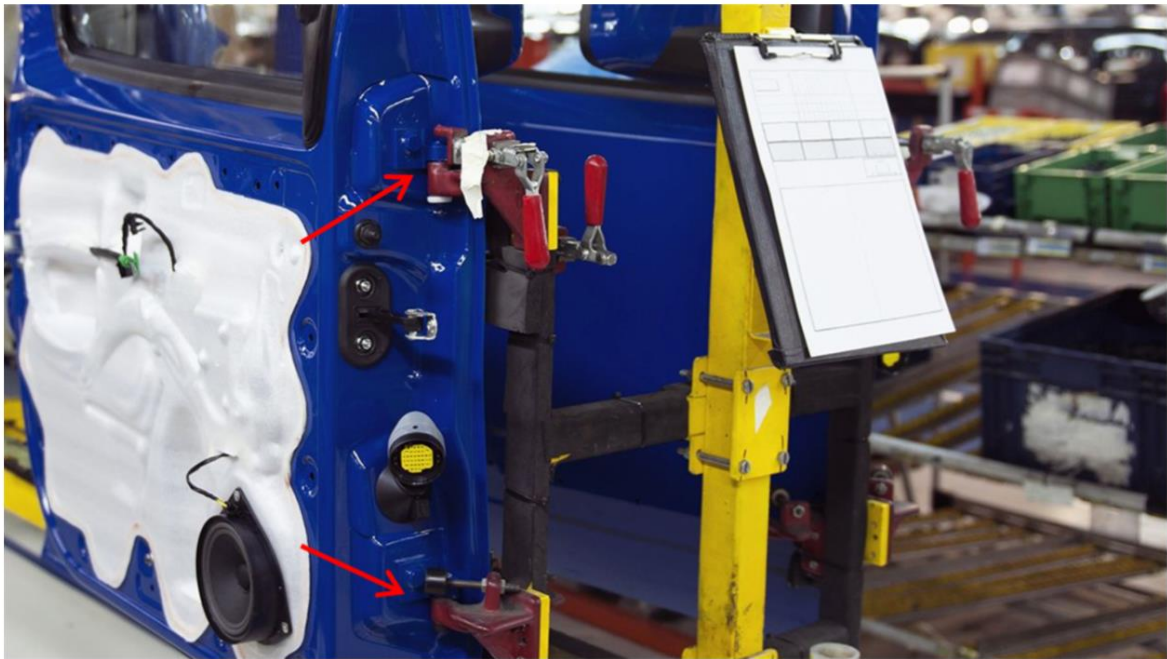
- Resist or avoid high temperatures in regions like the heat-affected zone
- Avoid degradation due to weld spatter or harsh chemicals
- Hold parts firmly in place during welding
- Repeatably position components to be welded throughout the fixture lifespan

- **Welding Fixture Core Functionality**
  - Harsh chemicals = sterke zuren

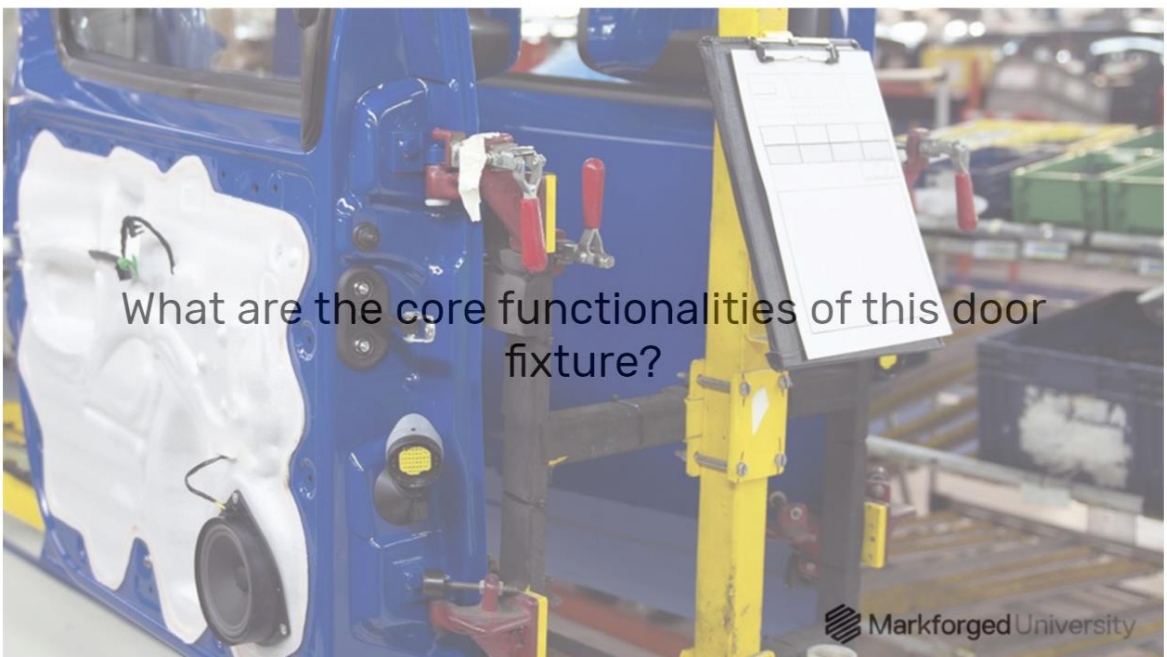
## Core Functions: Environmental Conditions

- Thermal effects
- Fluid immersion
- Harsh chemical exposure

- **Core Functions: Environmental Conditions**



- **Scenario 4: Car Door Assembly Fixture**



- **S4: What Are The Core Functionalities?**

## Car Door Assembly Fixture Core Functionality

- Holds heavy door around operators, can't fail during useful life
- Non-marring: can't scratch painted surfaces of finished part
- Structural rigidity to hold door in place as it's worked on
- Absorb routine impacts and loads due to life on plant floor

- **Car Door Assembly Fixture Core Functionality**

- Around = in de omgeving van.
- Non-marring = voorkomen beschadigen / niet in de war brengen.
- Rigidity = stijfheid.
- Impact = Uitwerking, invloed of effect.
- Load = Last.

## Core Functions: Success Specifications

- Tolerances
- Stiffness/elasticity
- Print yield
- Functional yield
- Cycles to failure

- **Car Door Assembly Fixture Core Functionality**

- Yield = opbrengst.

☰ C2.3 - Design for FFF+CFF Part 1

## Recap: Core Functionality Categories

- Part Interactions
- Loading Conditions
- Environmental Conditions
- Success Specifications



- **Review: Core Functionality Categories**

- Loading Conditions = What type and directions of load.

☰ C2.3 - Design for FFF+CFF Part 1

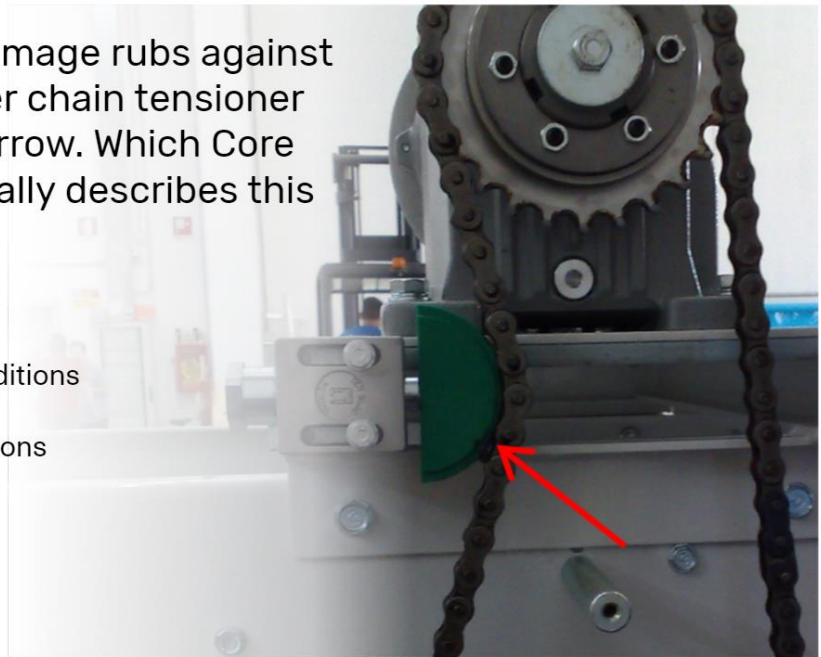
## Module Review



- **Module Review**

The chain in this image rubs against the green polymer chain tensioner marked with an arrow. Which Core Function specifically describes this contact?

- Part Interactions
- Environmental Conditions
- Success Specifications
- Loading Conditions

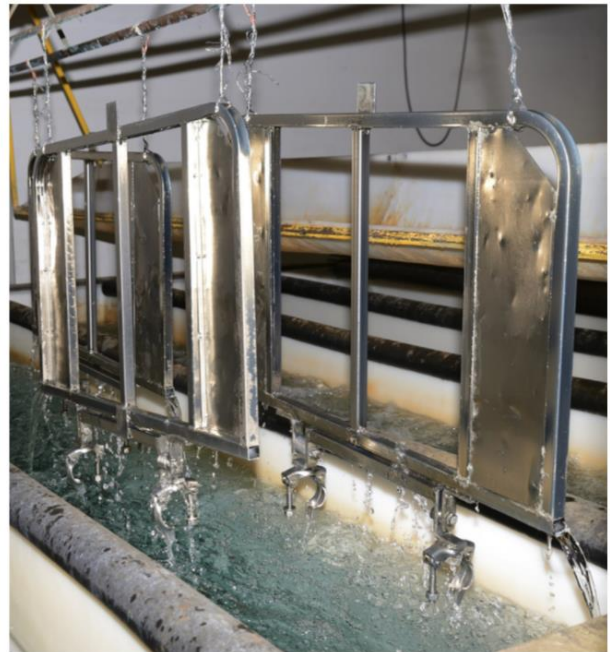


Put the following steps for taking a defined problem to a functional minimum viable part in order:

1. Identify core functionality
2. First pass design/existing CAD
3. Revise design to meet core functionality
4. Import into Eiger
5. First pass print settings and material selection
6. Print and test

What category of functional requirements would you be most concerned with if you were creating a fixture submersion in a chemical plating bath like this one?

- Part Interactions
- Loading Conditions
- Success Specifications
- Environmental Conditions




- Submersion = Onderdompeling

### Results

Your Score:	100% (30 points)
Passing Score:	80% (24 points)

---

### Result:

 Congratulations, you passed.

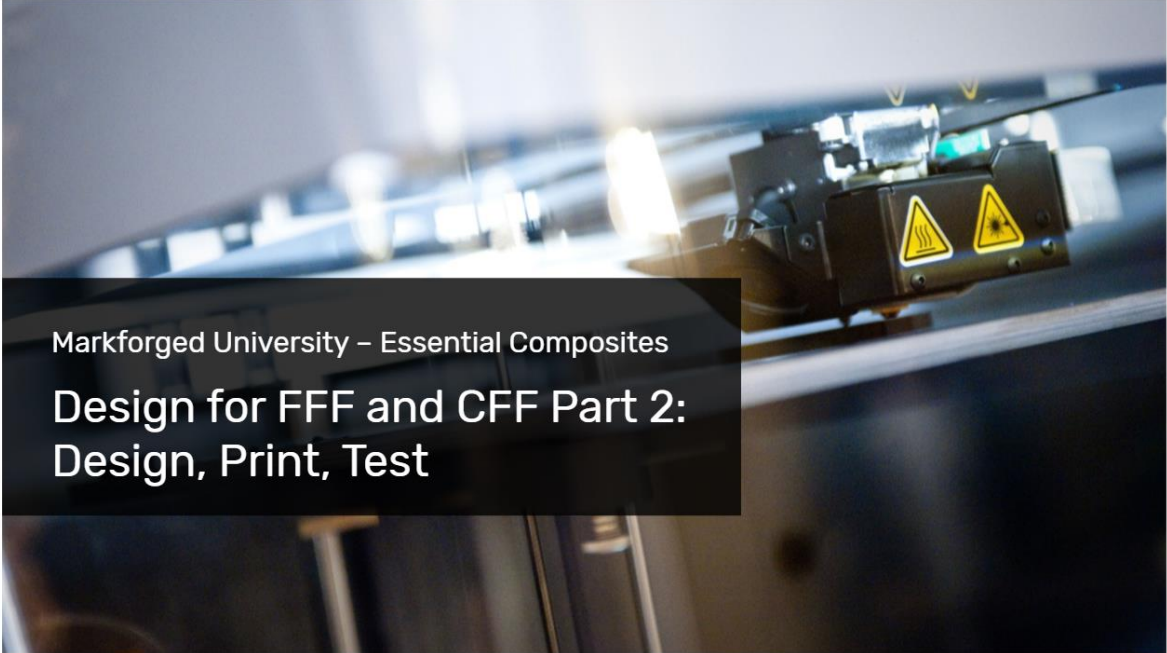
[Finish Module](#)

[Review Quiz](#)



## C2.4 – Design for FFF and CFF Part 2

☰ C2.4 - Design for FFF+CFF Part 2 RESOURCES



Markforged University – Essential Composites  
**Design for FFF and CFF Part 2:  
Design, Print, Test**

- **Design for FFF and CFF Part 2**


☰ C2.4 - Design for FFF+CFF Part 2

# Module Overview

Design Example: CNC Tube Bending Die

Unit Testing Workflow

DfAM Case Study: End of Arm Tooling

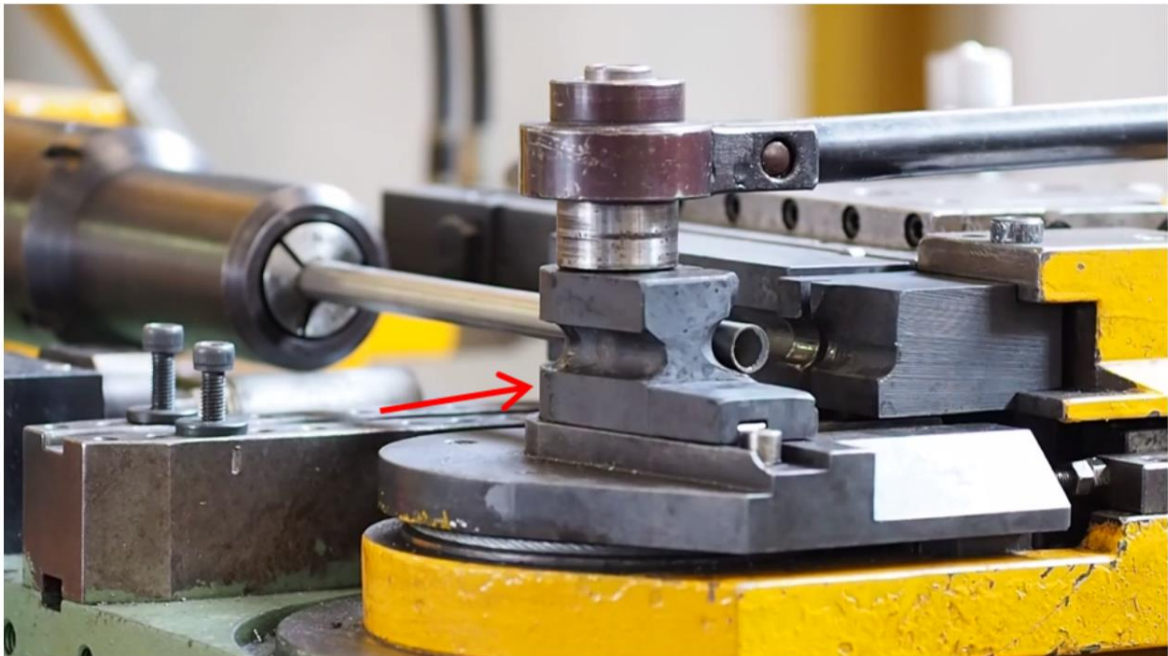
 Markforged University

- **Module Overview**
  - DfAM = Design for Additive Manufacturing

## Problem → Part Workflow

1. Identify **core functionality**
2. First pass **design/block CAD**
3. **Revise design** to meet core functionality
4. Import into **Eiger**
5. First pass **print settings** and material **selection**
6. **Print and test**

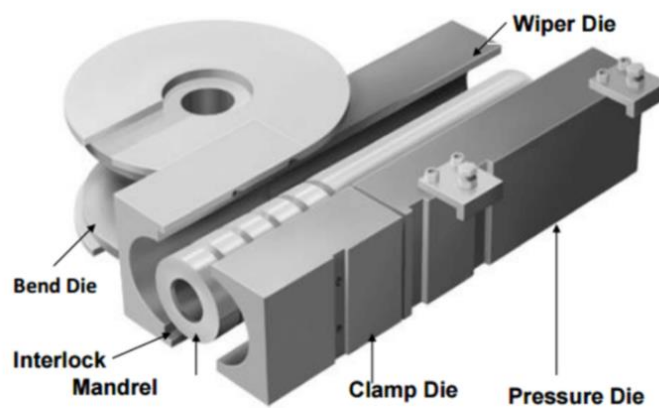
- **Step 2/3: Initial Designs and Design Revision**
  - Initial Design = Eerste ontwerp.



- **Video: CNC Tube Bending**
  - Lead Time = Doorlooptijd.



## Design Study: CNC Tube Bending Die

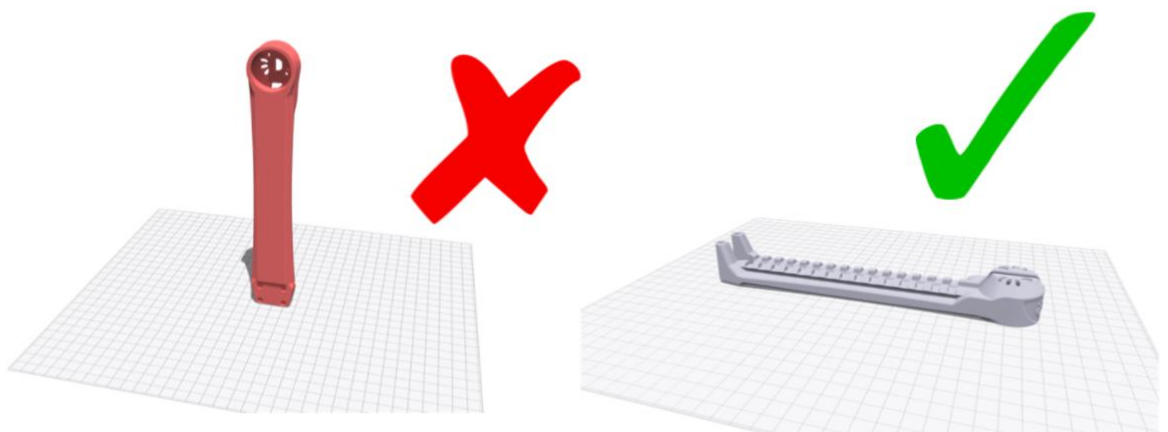


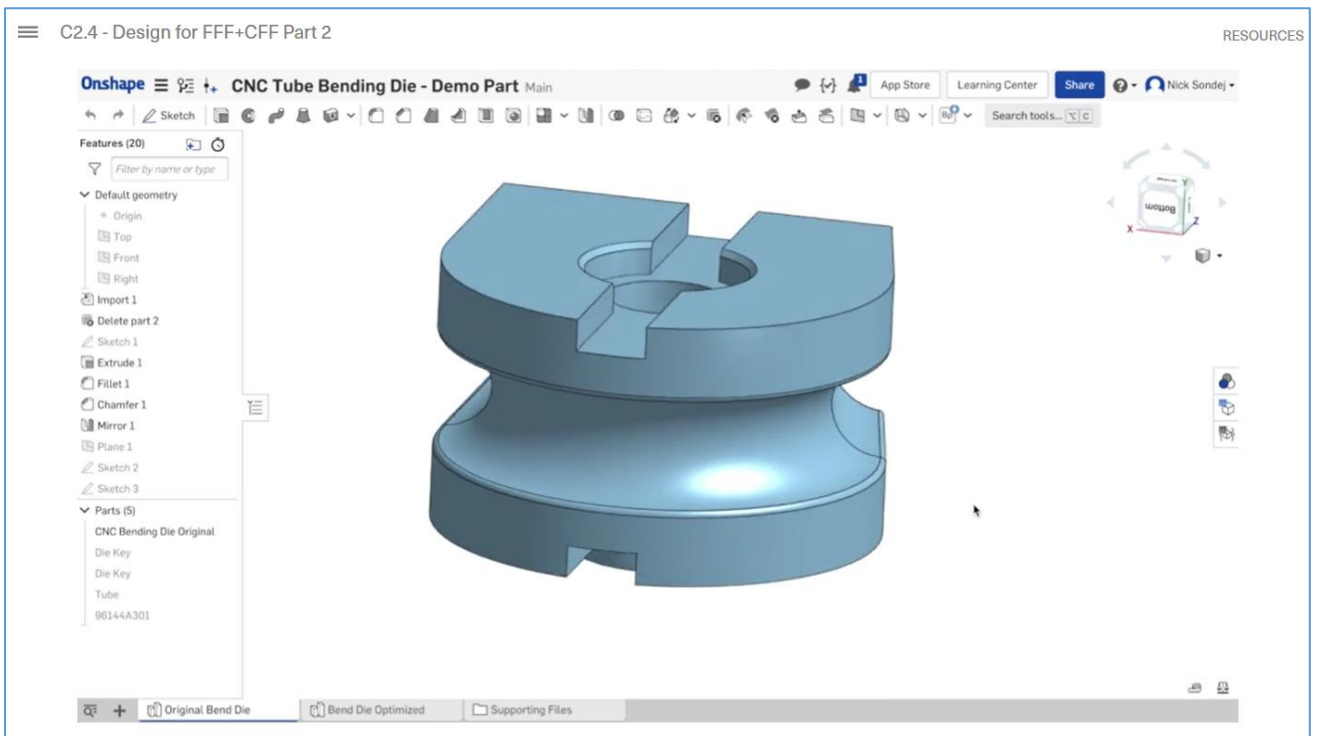
- **Design Study: CNC Tube Bending Die**
  - Vertaald uit het Engels-Een doorn, doorn of priegel is een zacht taps toelopende cilinder waartegen materiaal kan worden gesmeed of gevormd, of een van een flens voorziene of taps toelopende of van schroefdraad voorziene staaf die een werkstuk grijpt dat op een draaibank moet worden bewerkt.



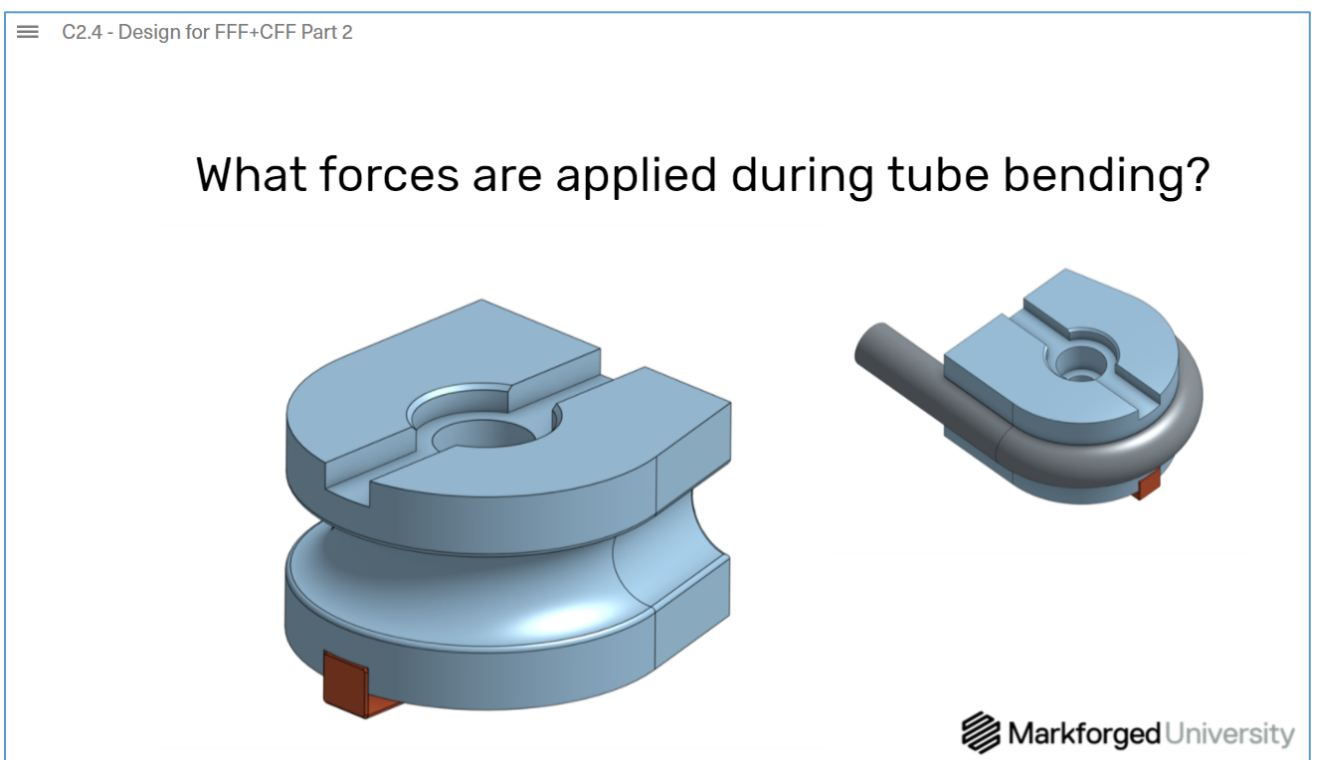
- **Loading Conditions Drive Print Orientation**

## Loading Conditions Drive Print Orientation





- **CAD Demo: Existing CAD Model**

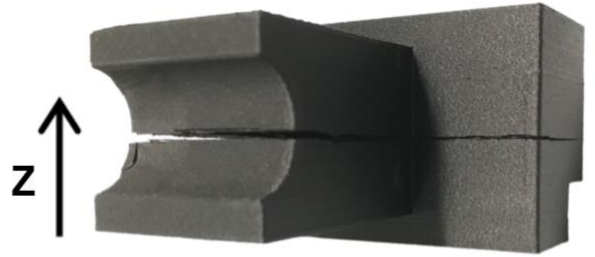


- **Tube Bending Forces**



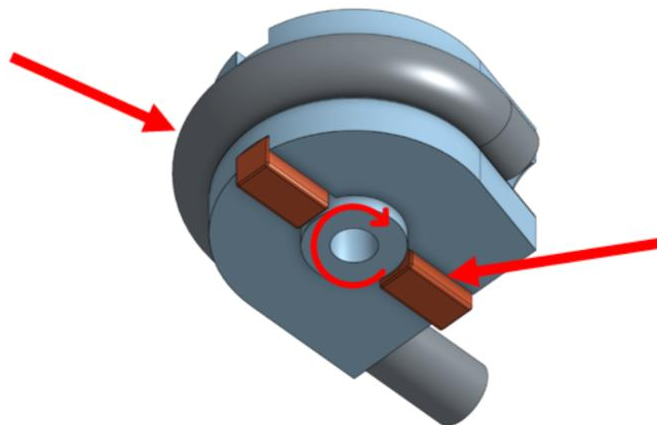
## Remember This Part?

Failure typically between layers  
DFM for 3D printing not considered  
Resolved via intentional re-design



- **Remember This Part?**

Tube  
undergoing  
bending

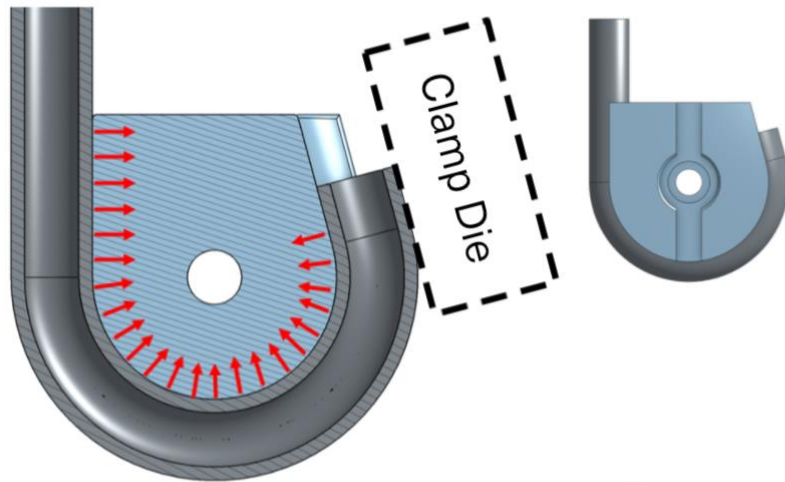


Machine keys  
transfer  
machine torque  
to bending die

- **Operation of the Die**

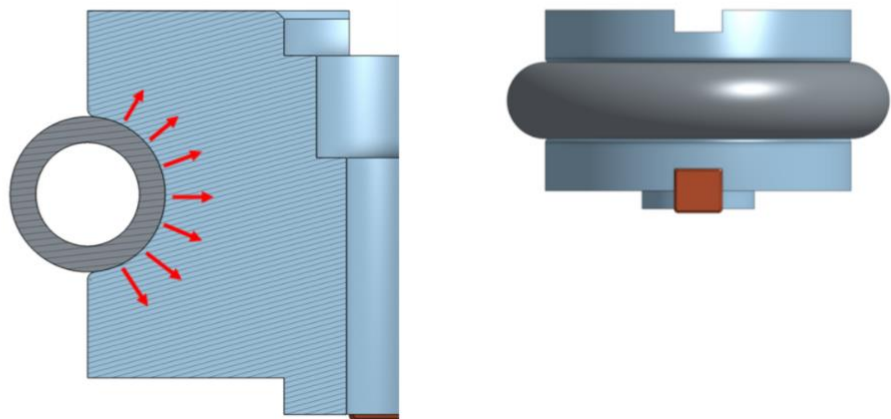


## Applied Forces - Compression



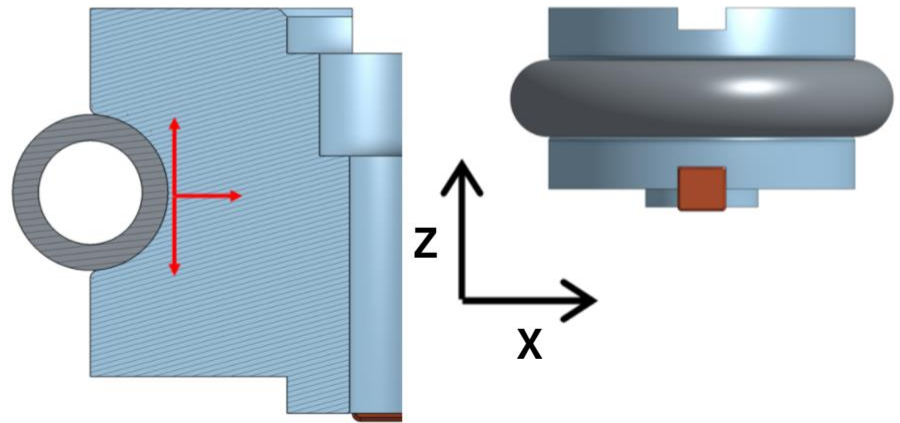
- **Applied Forces – Compression**

## Applied Forces - Expansion



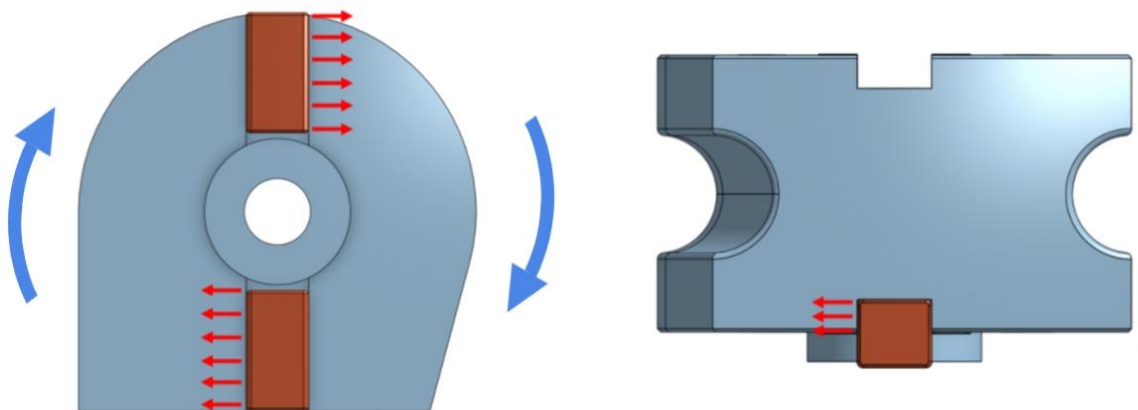
- **Applied Forces – Expansion**

## Applied Forces - Expansion



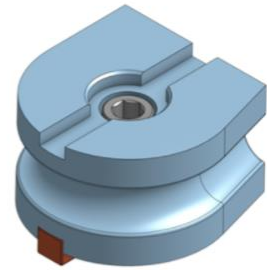
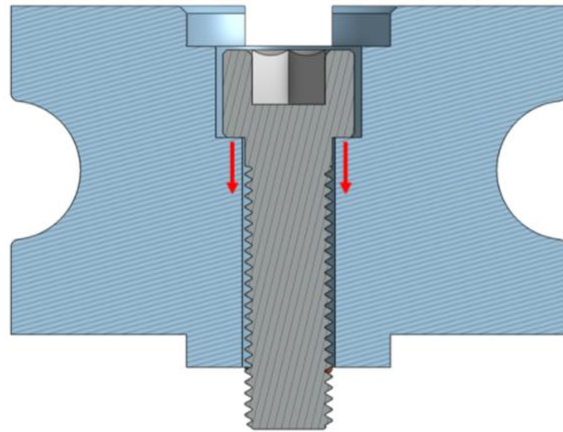
- Isotropic material: Crack between layers (Z-axis)

## Applied Forces - Torque



- Applied Forces – Torque

## Applied Forces - Bolt Compression



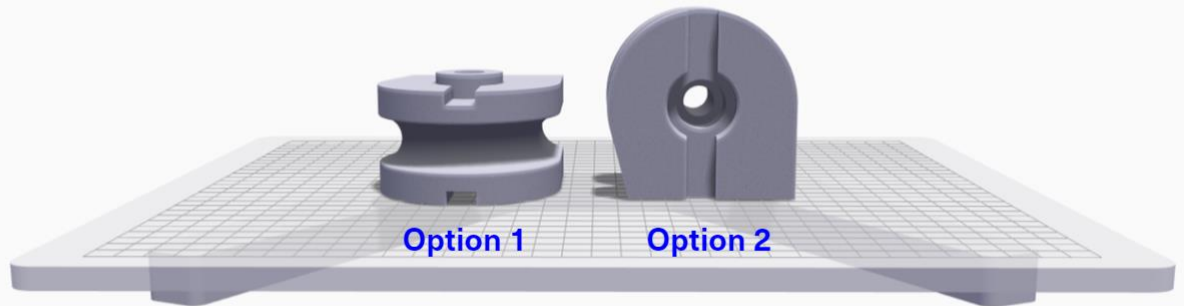
- **Applied Forces – Bolt Compression**

## How should we orient this part?

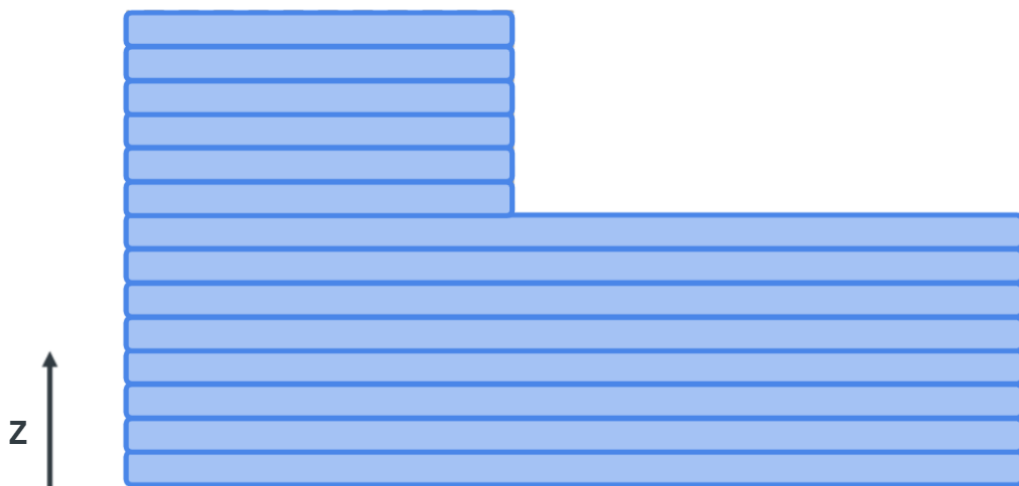
[See Options](#)

- **How should we orient this part?**

How should we orient this part?

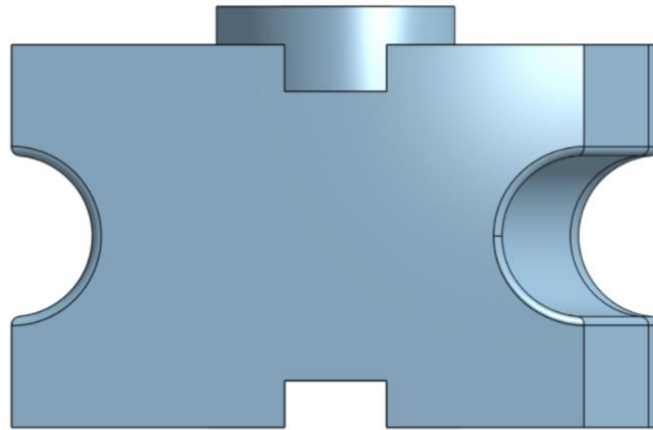


Remember: Build Parts One Layer at a Time



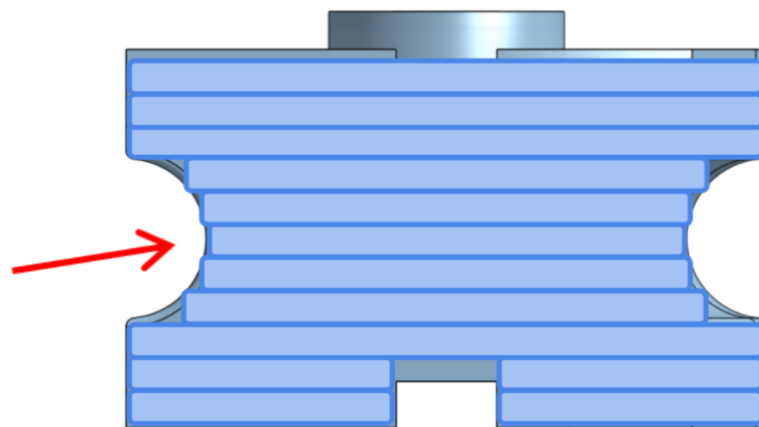
- Remember: Build Parts One Layer at a Time

### Option 1

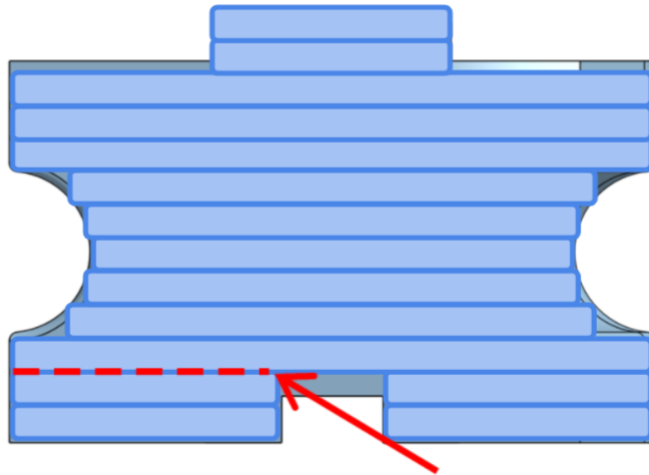


- **Option 1 – Print Construction**

### Option 1

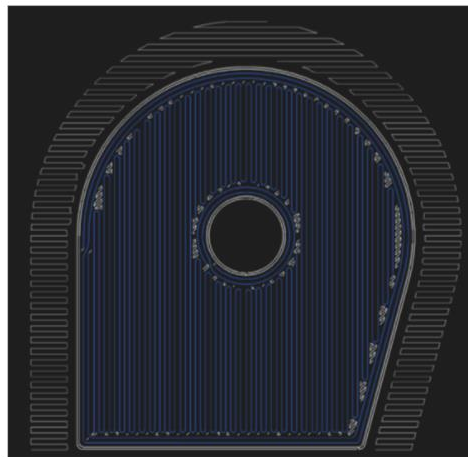


### Option 1



- Shear Force.

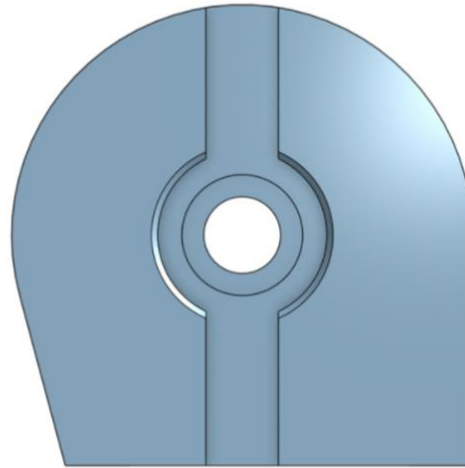
### Option 1 – Fiber



- Option 1 – Fiber

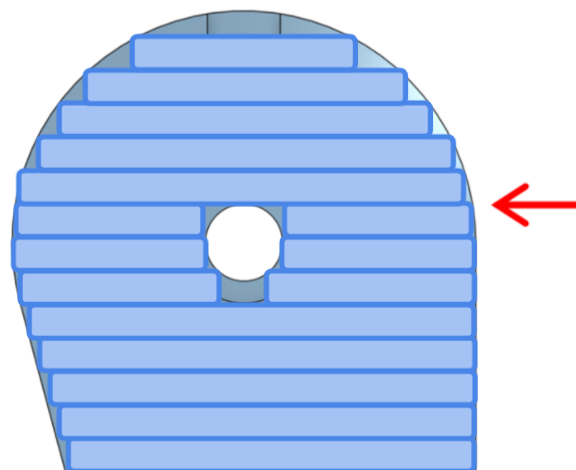


## Option 2



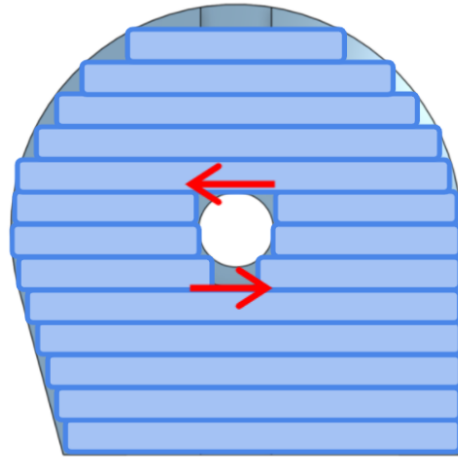
- **Option 2 – Print Construction**

## Option 2

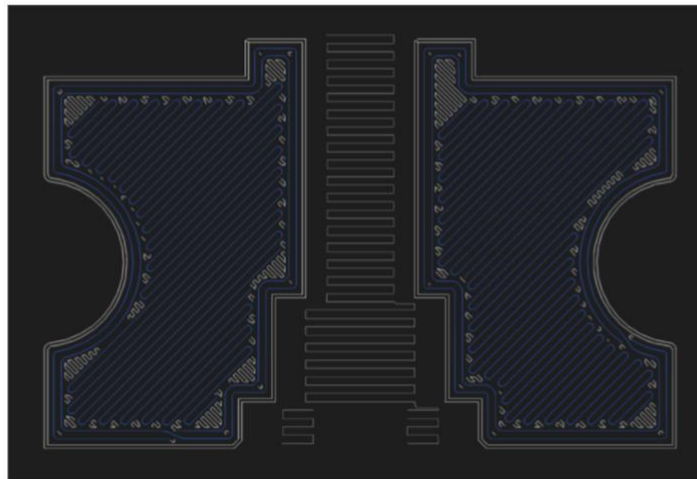


- Shear Forces

## Option 2

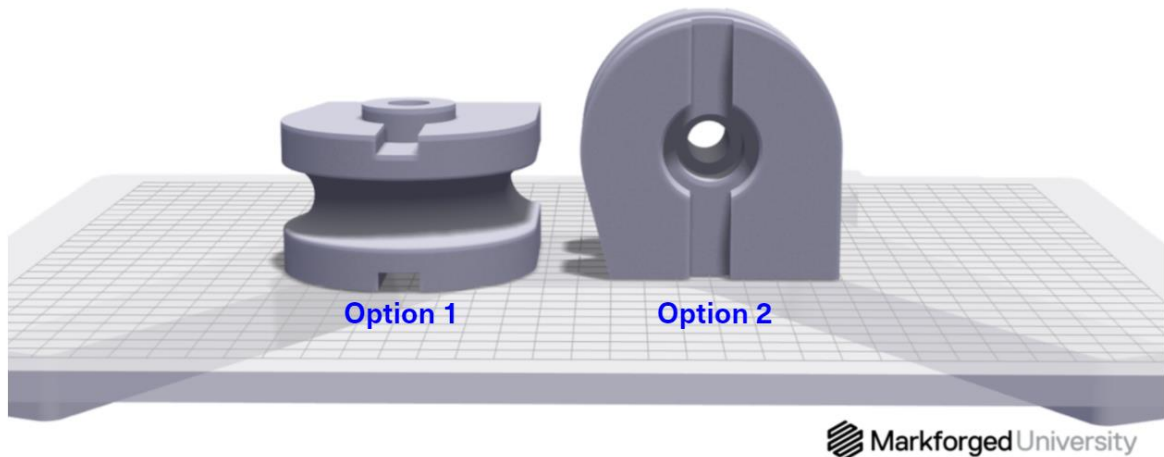


## Option 2 – Fiber



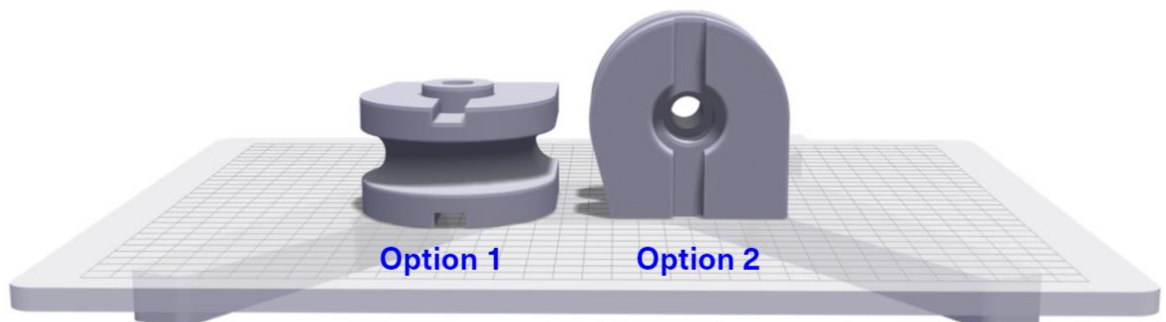
- Option 2 – Fiber

If we can't adjust our design, what orientation would you choose?



- What Should We Choose?

A: It's always an engineering tradeoff



- Option 1 has better accuracy and surface finish in the bending curvature
- Option 2 better resists the compression + expansion forces from the tube

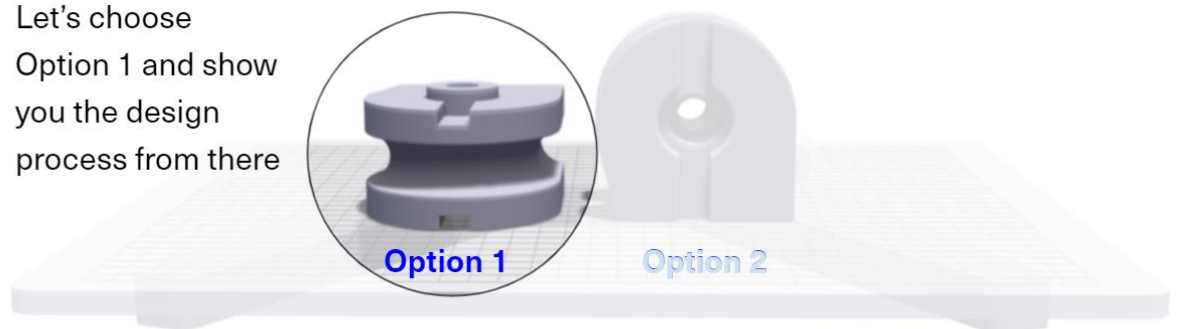
- A: It's always an engineering tradeoff
  - Tradeoff = Compromis
  - Curvature = Kromming

Now, let's choose a print orientation and adjust our design to meet our functional requirements

- **Now, let's adjust our design**

How should we orient this part?

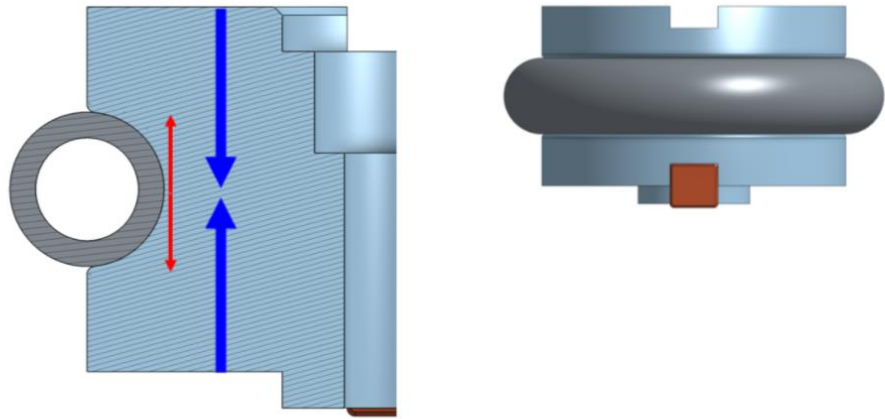
Let's choose Option 1 and show you the design process from there



- **How should we orient this part?**

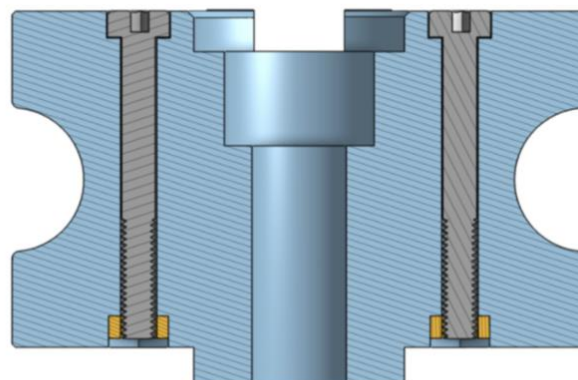
## Force #1: Expansion

How can we generate a restoring force with a design change?



- **Force #1: Expansion**

## Bolts Strengthen the Z-axis

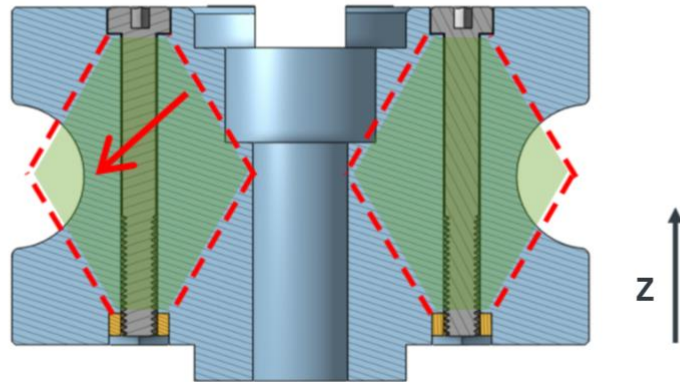


**Tensile Strength**  
M5 bolt: ~1100 MPa  
Onyx: 36 MPa

- **Bolts Strengthen the Z-axis**

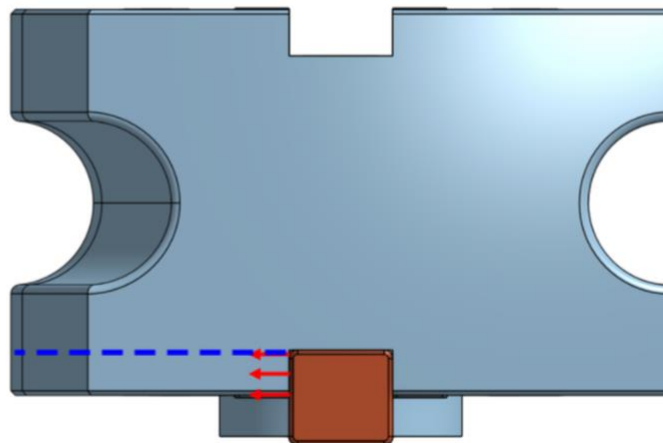
## Bolts Strengthen the Z-axis

Stress cone between bolt head and nut adds extra tensile strength in Z-axis



- Insure Area intending to reinforce falls within the cone

## Force #2: Shear

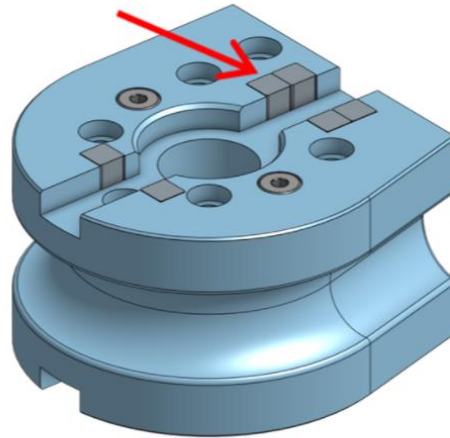


How can we avoid the die failing between layers?

- Force #2: Shear

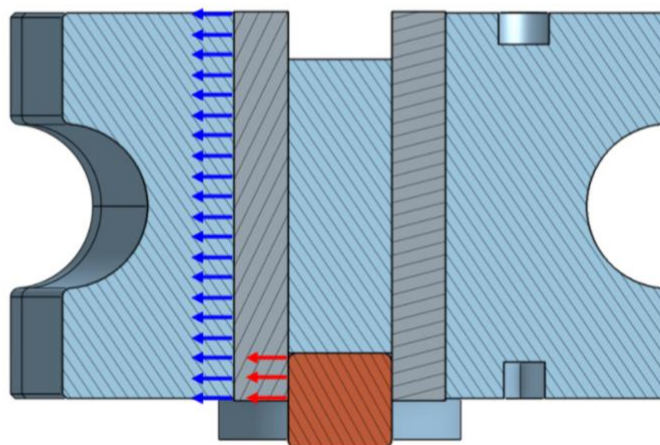


## Force #2: Shear



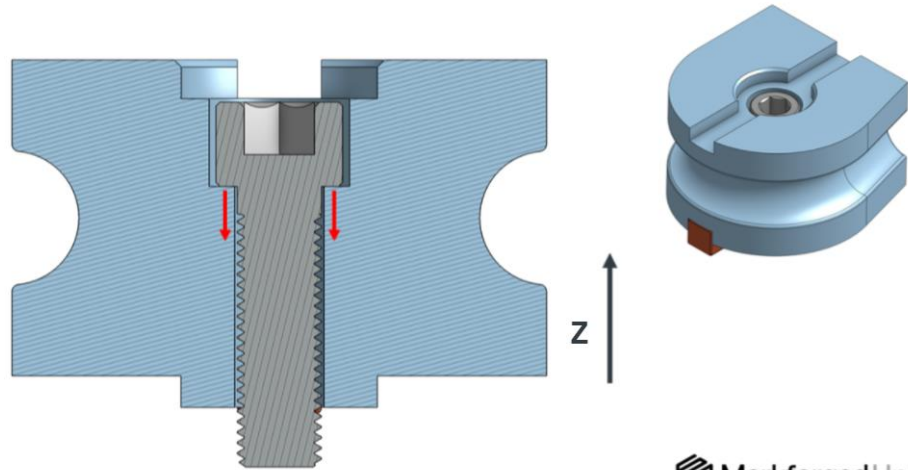
- **Steel Stock Distributes Shear Forces**
  - Shear Forces = Afschuifkrachten

## Force #2: Shear

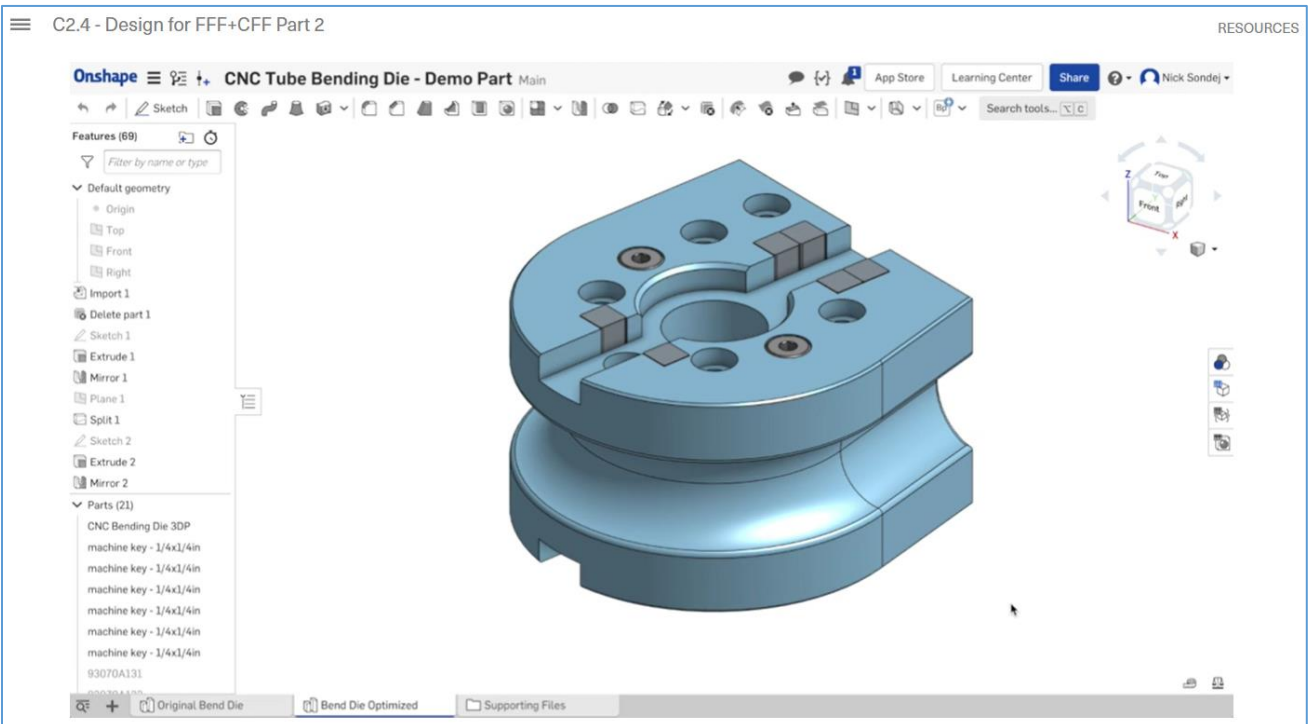


Shear force is distributed across all layers by machine keys

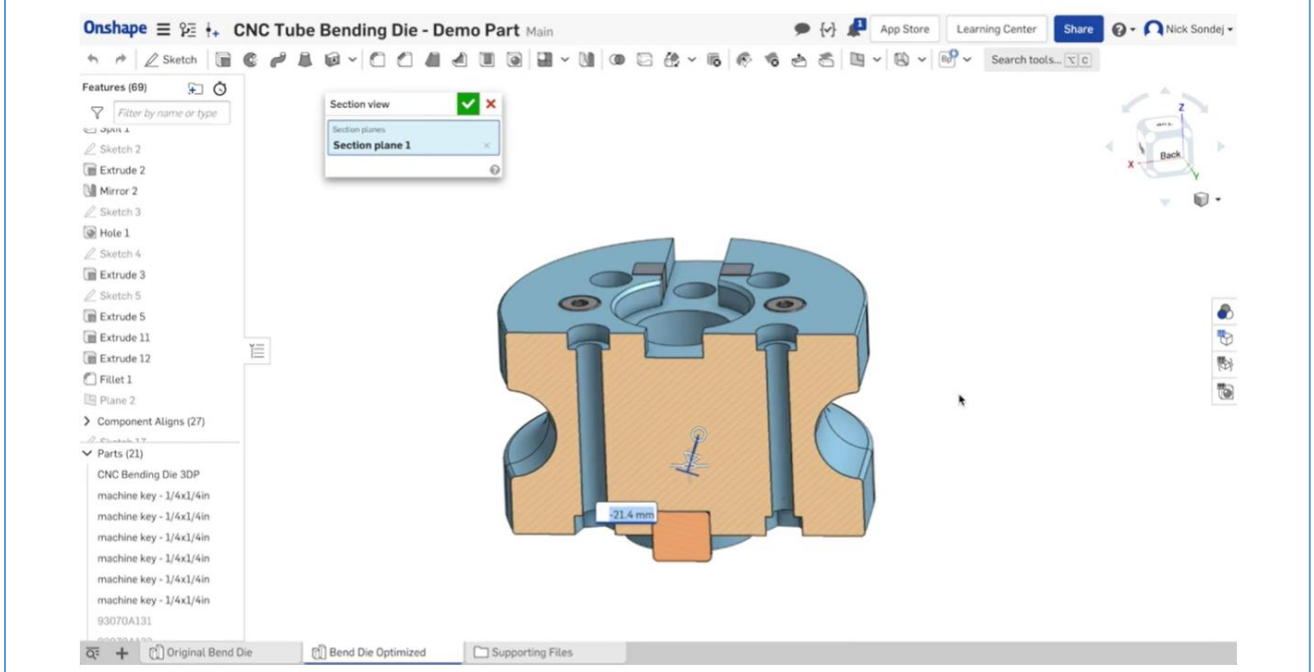
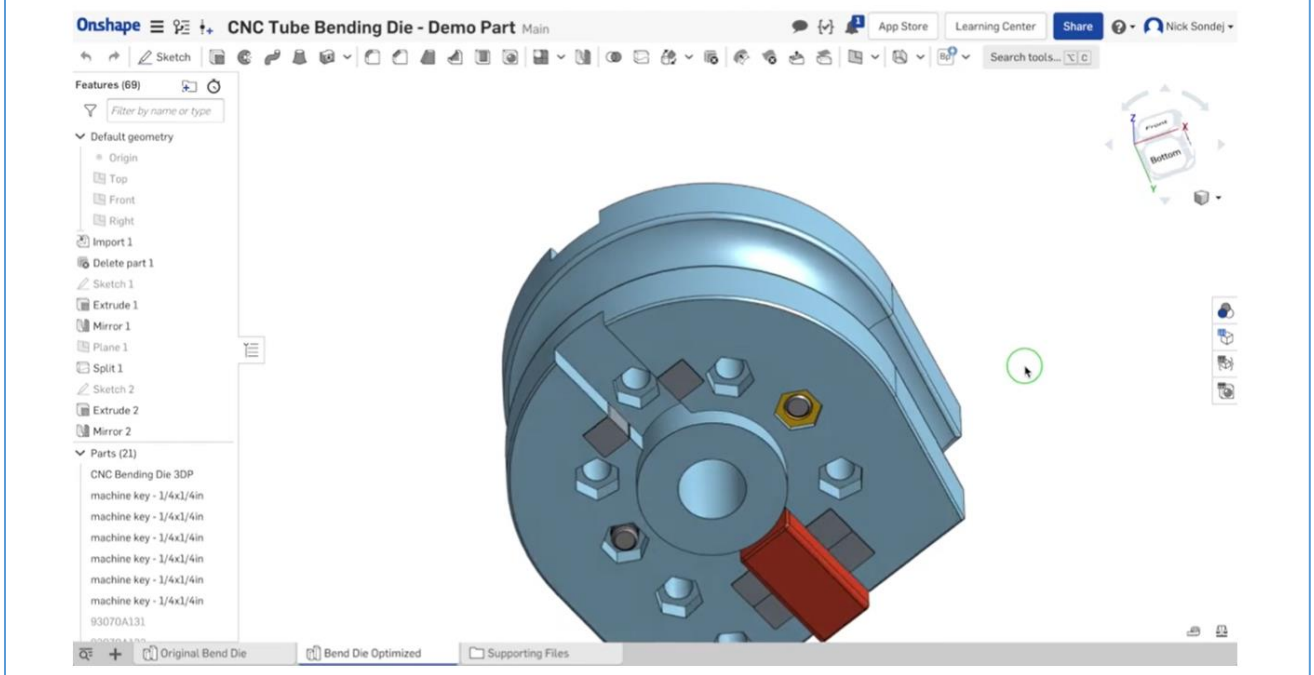
### Force 3: Center Bolt Compression

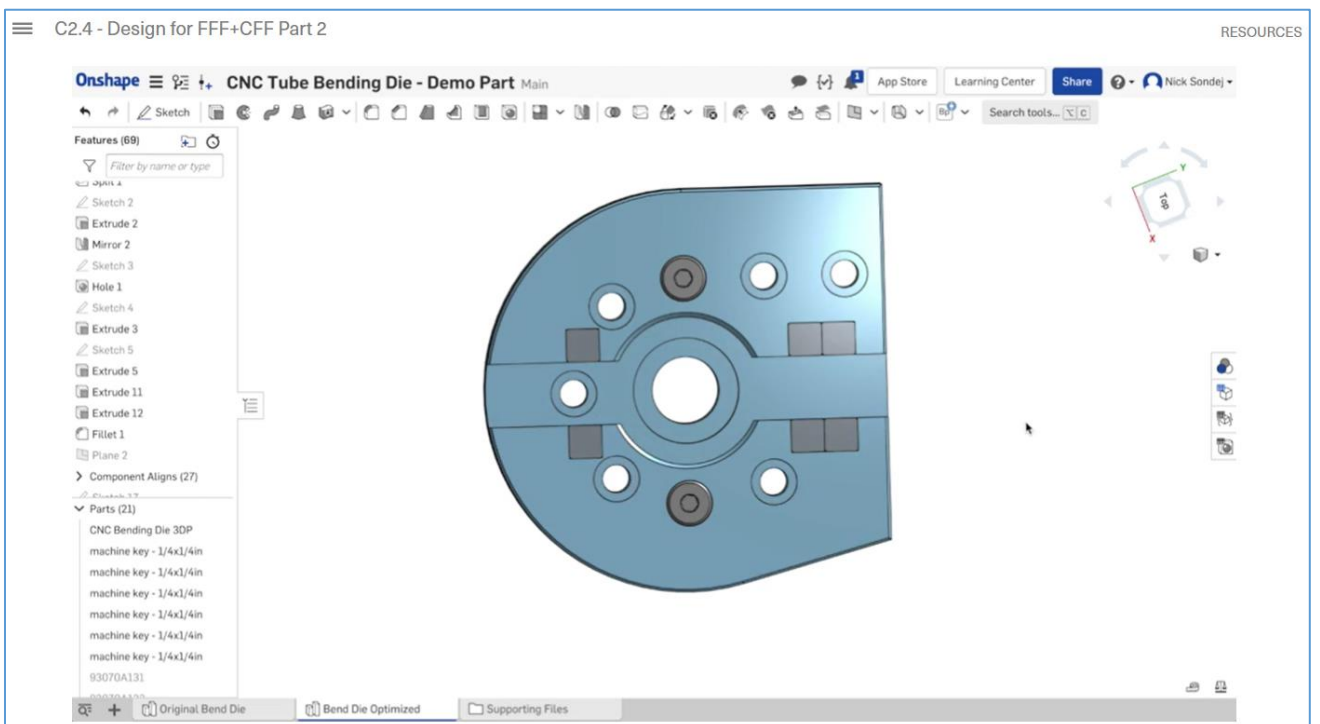
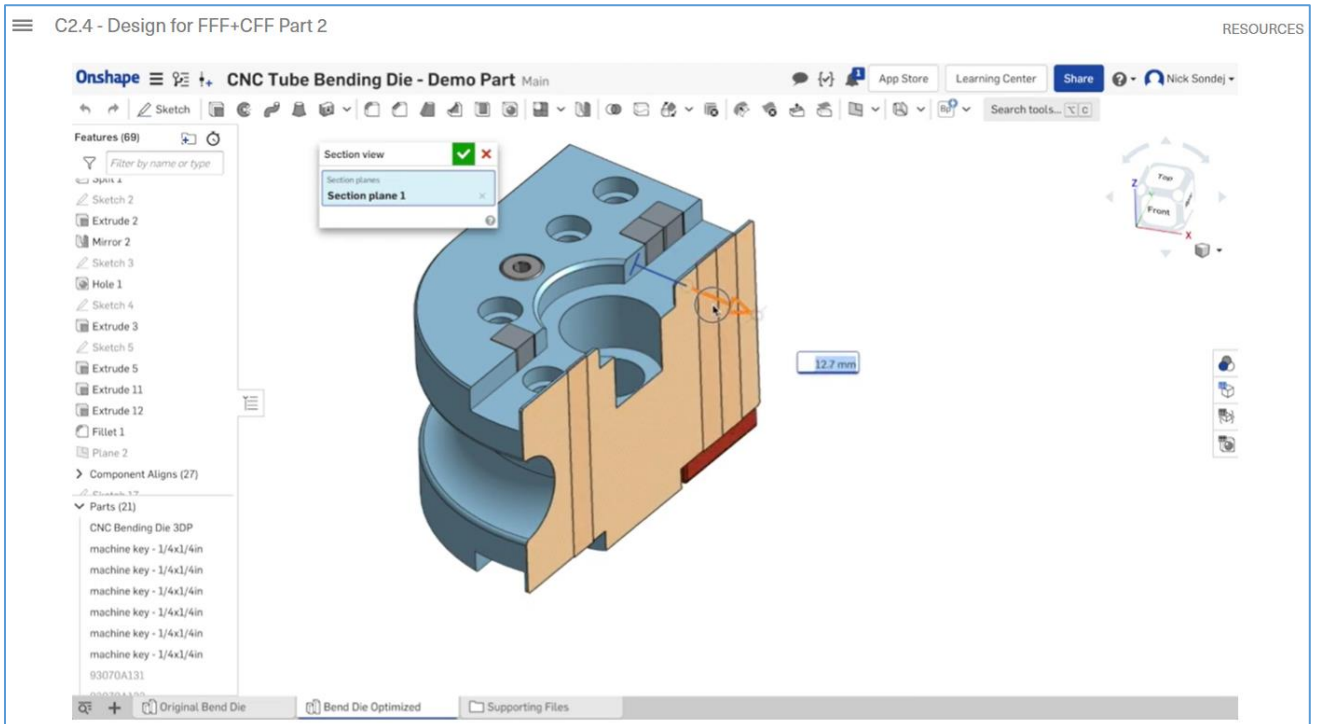


- **Force #3: Center Bolt Compression**
  - Could also redesign with a flanged bushing, but in this case not really necessary



- **CAD Demo: Revising an Existing Design**





- Drive fit.

## CAD DEMO

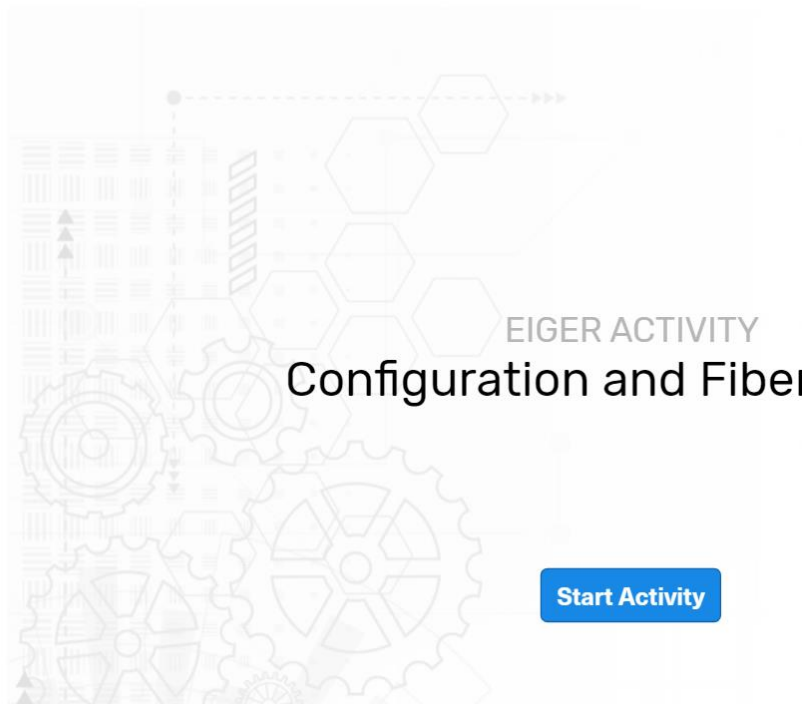
# Revising an Existing Design

- **CAD Demo: Revising an Existing Design**

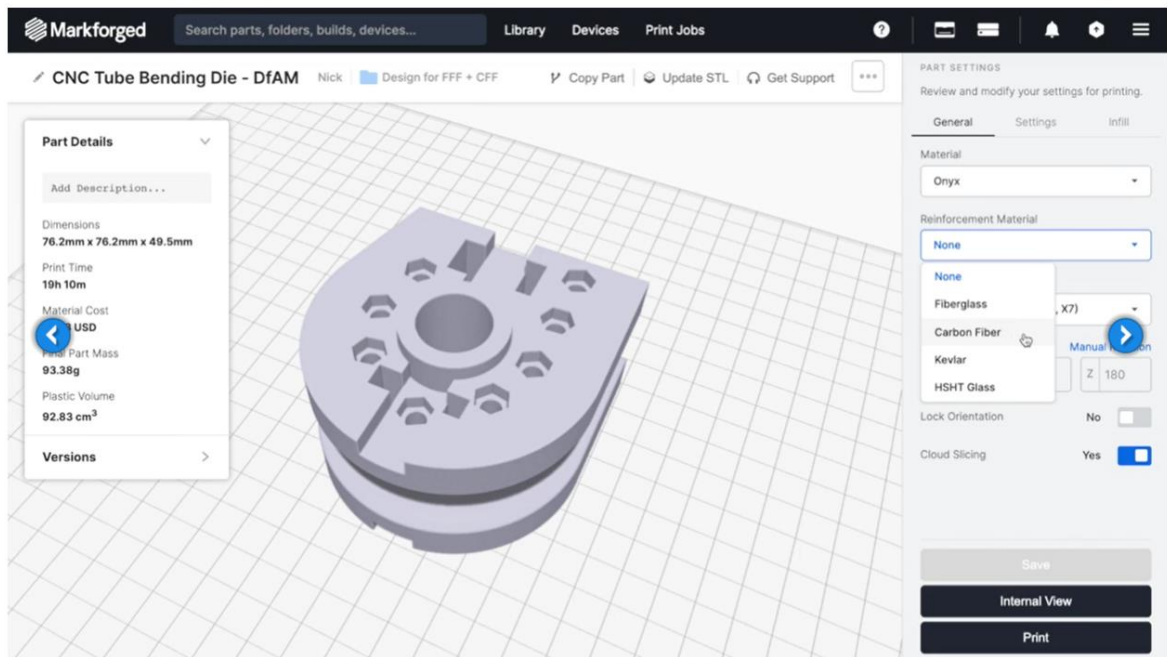
## Problem → Part Workflow

1. Identify **core functionality**
2. First pass **design/block CAD**
3. **Revise design** to meet core functionality
4. Import into **Eiger**
5. First pass **print settings** and material **selection**
6. **Print and test**

- **Step 4/5: Eiger Configuration**

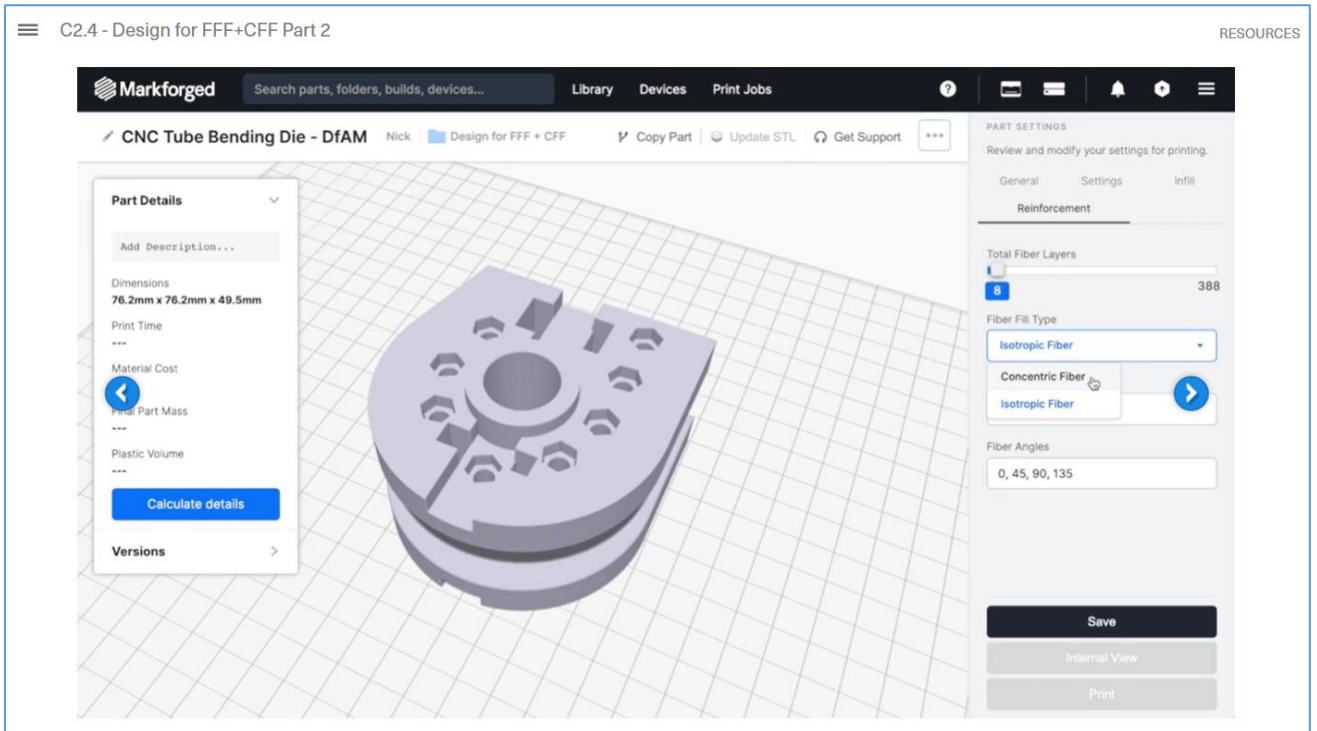


- Eiger Activity: Configuration and Fiber Layout

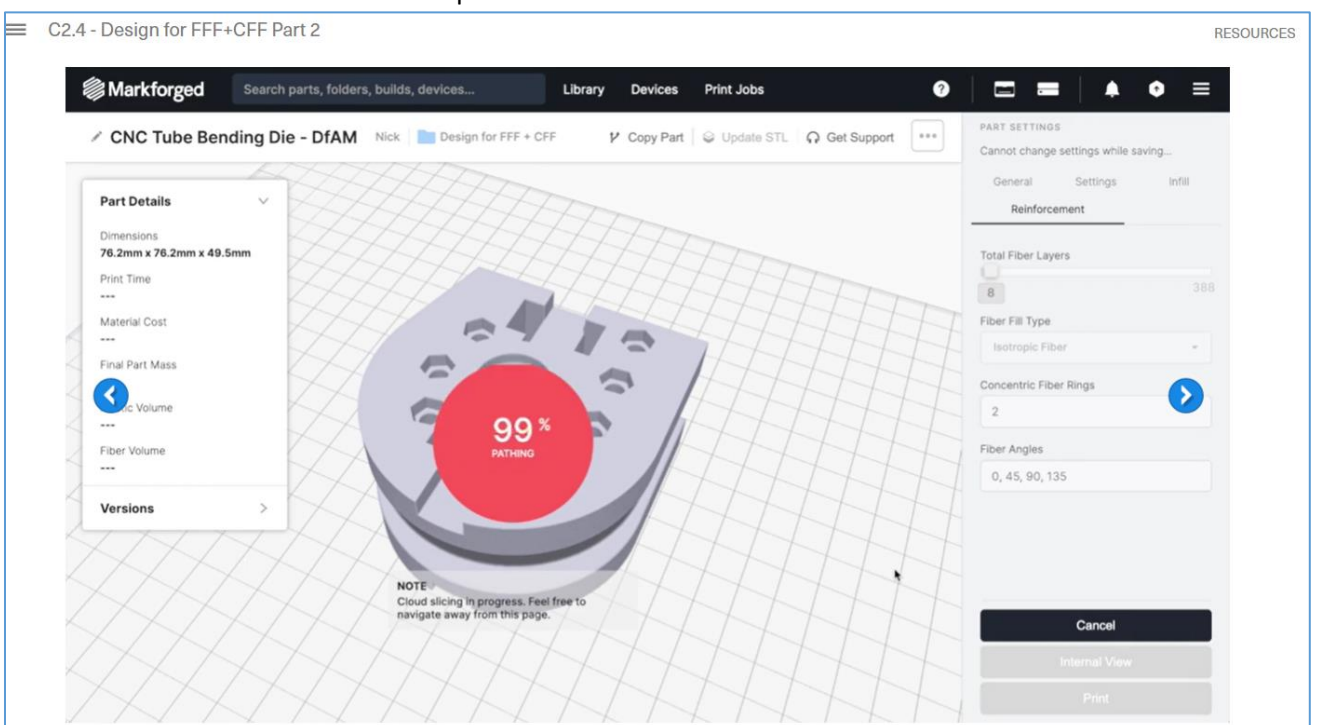


- Reinforcement Material: Highest strength > Carbon Fiber

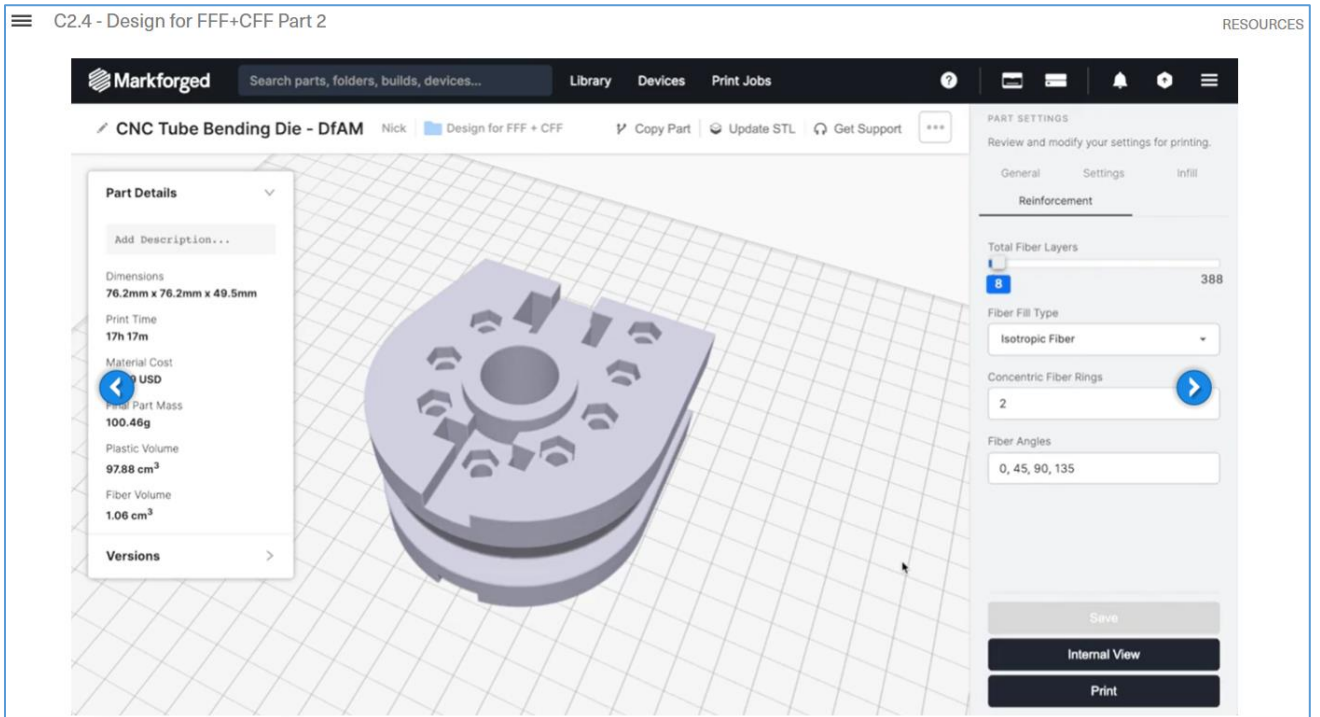




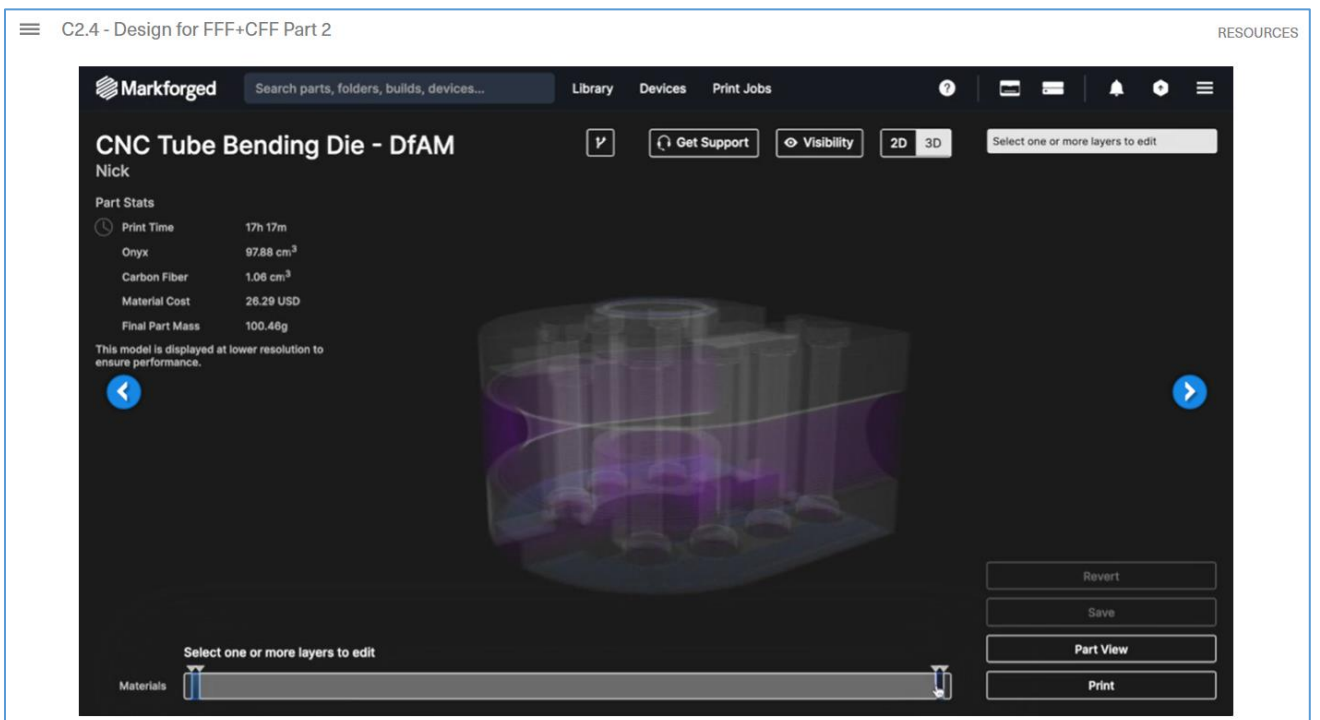
○ Reinforcement: Isotropic Fiber



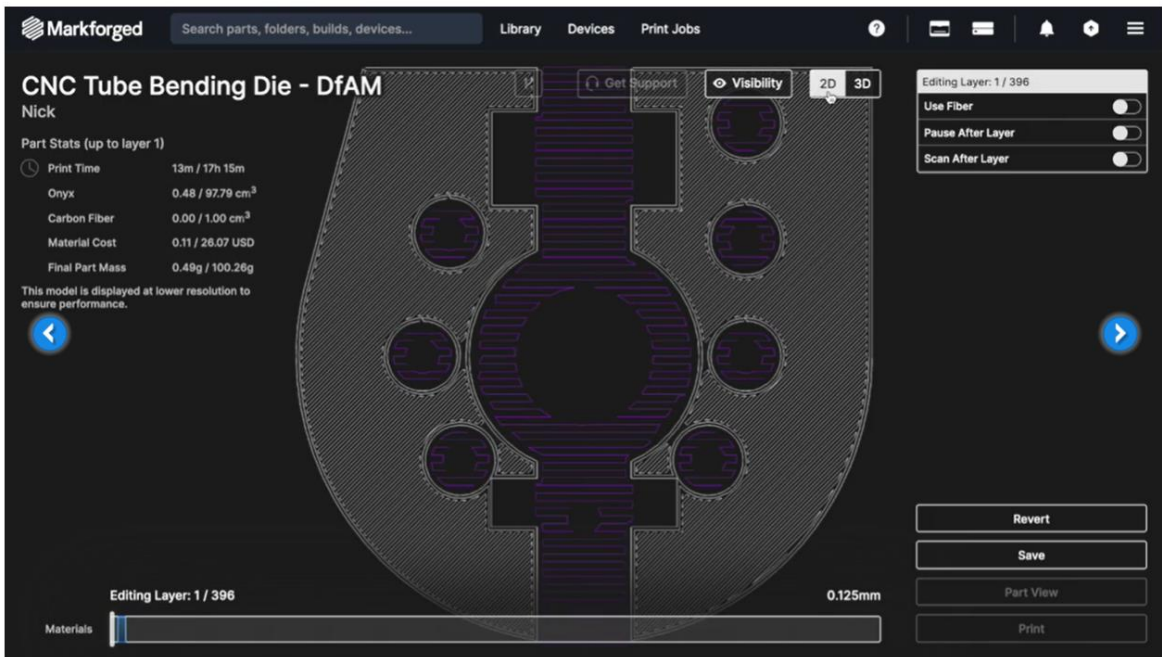
○ Save it.



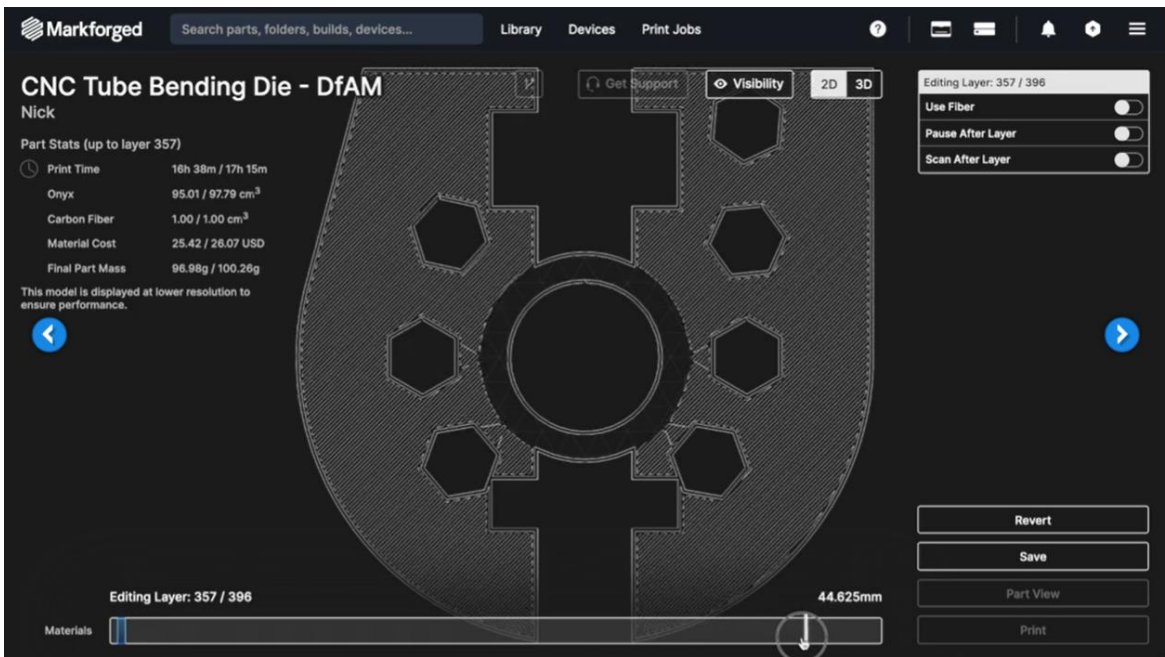
- Click on Internal View Button



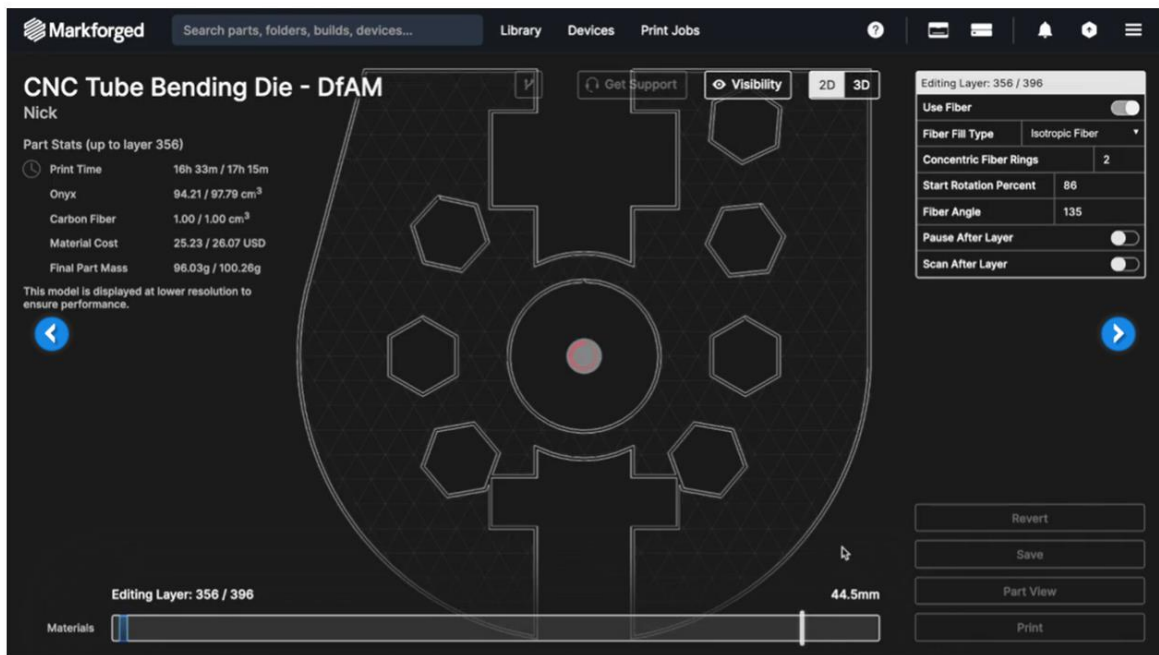
- Deleting a group (at the top).



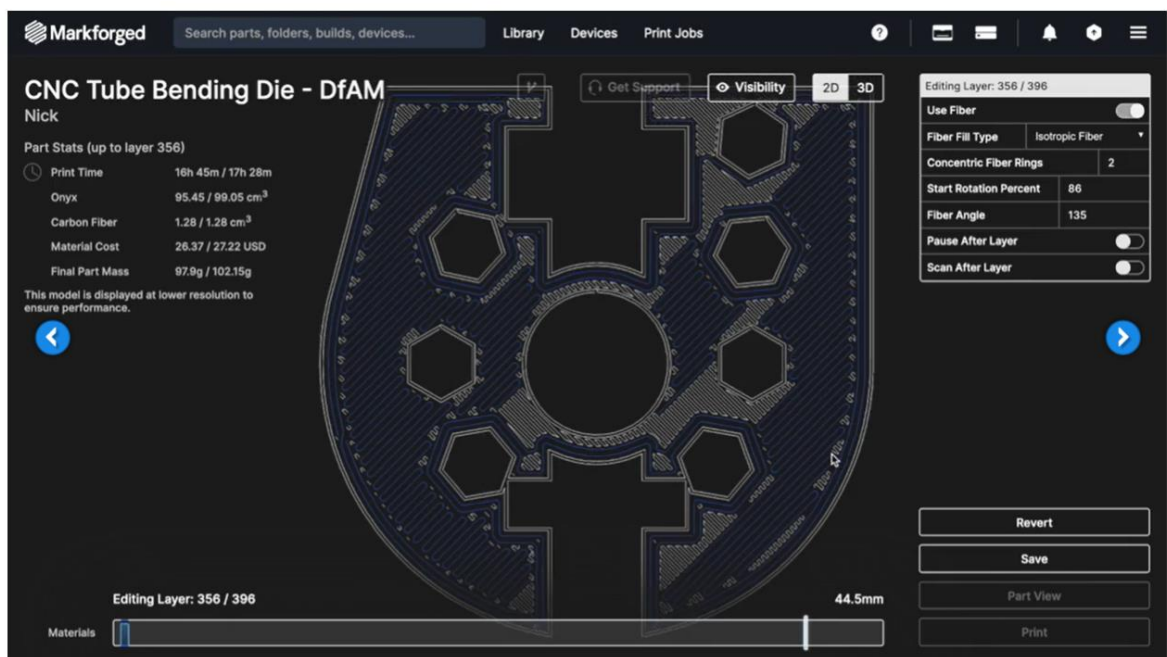
- Choose 2D view.



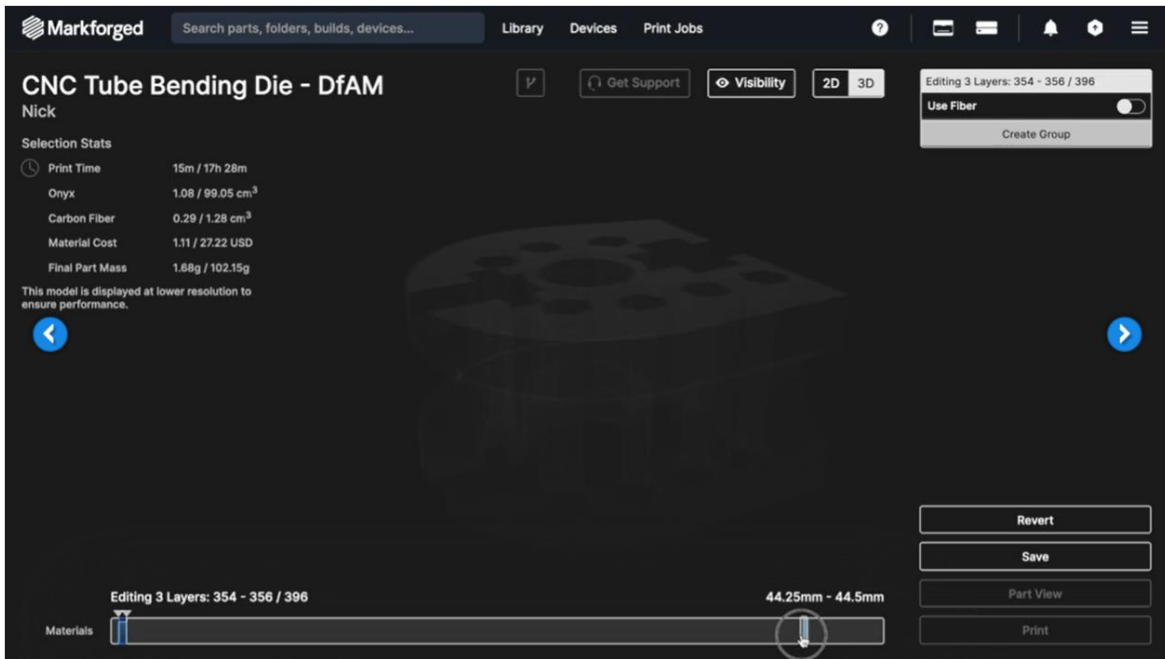
- Look for the Top of the Roof.



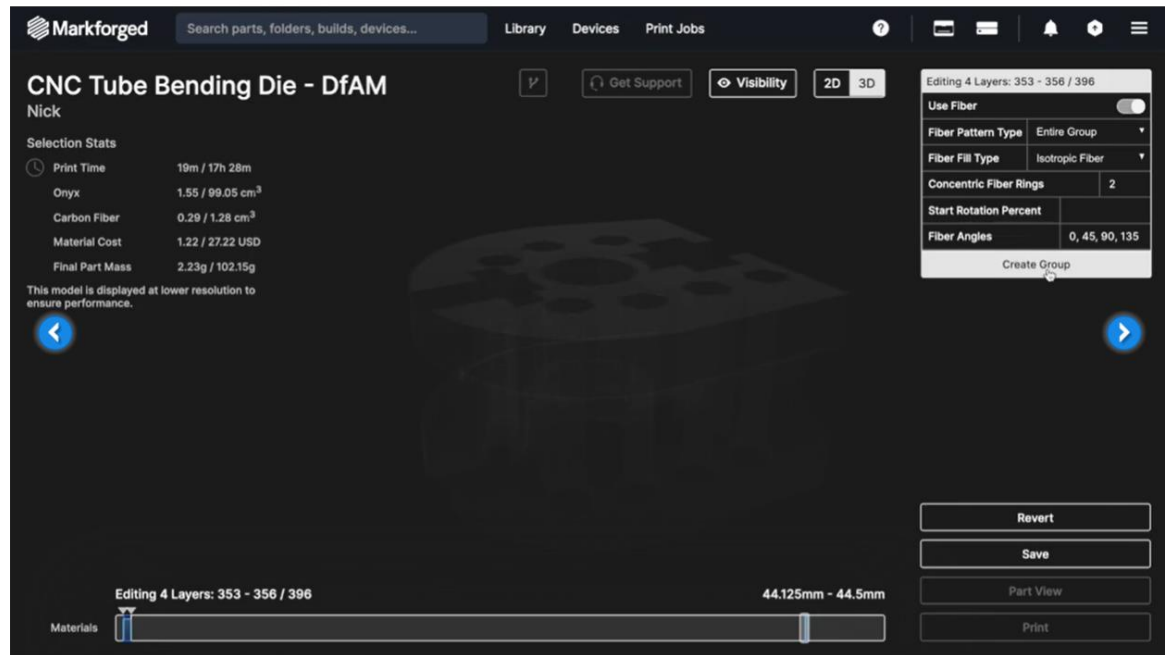
- Go a layer below the floorlayer.



- Toggle on.

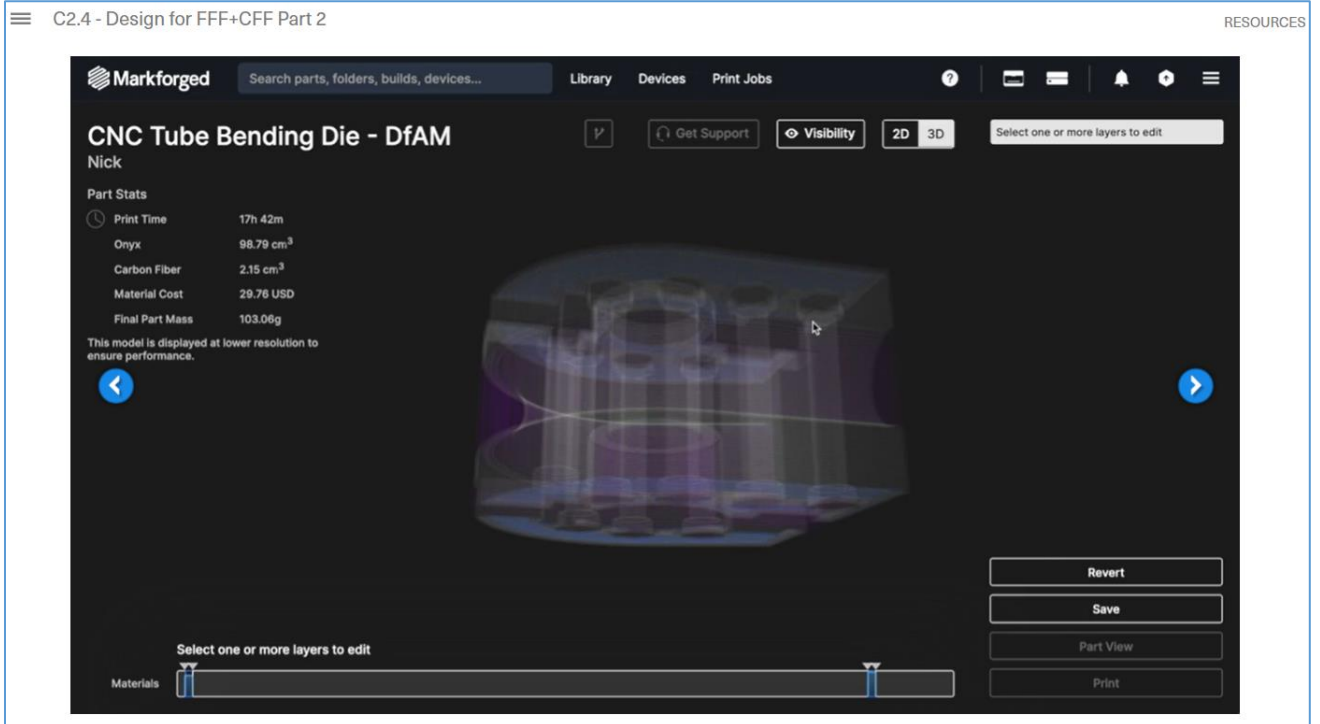


- Back in the 3D View: Drag down 4 layers for a selection.

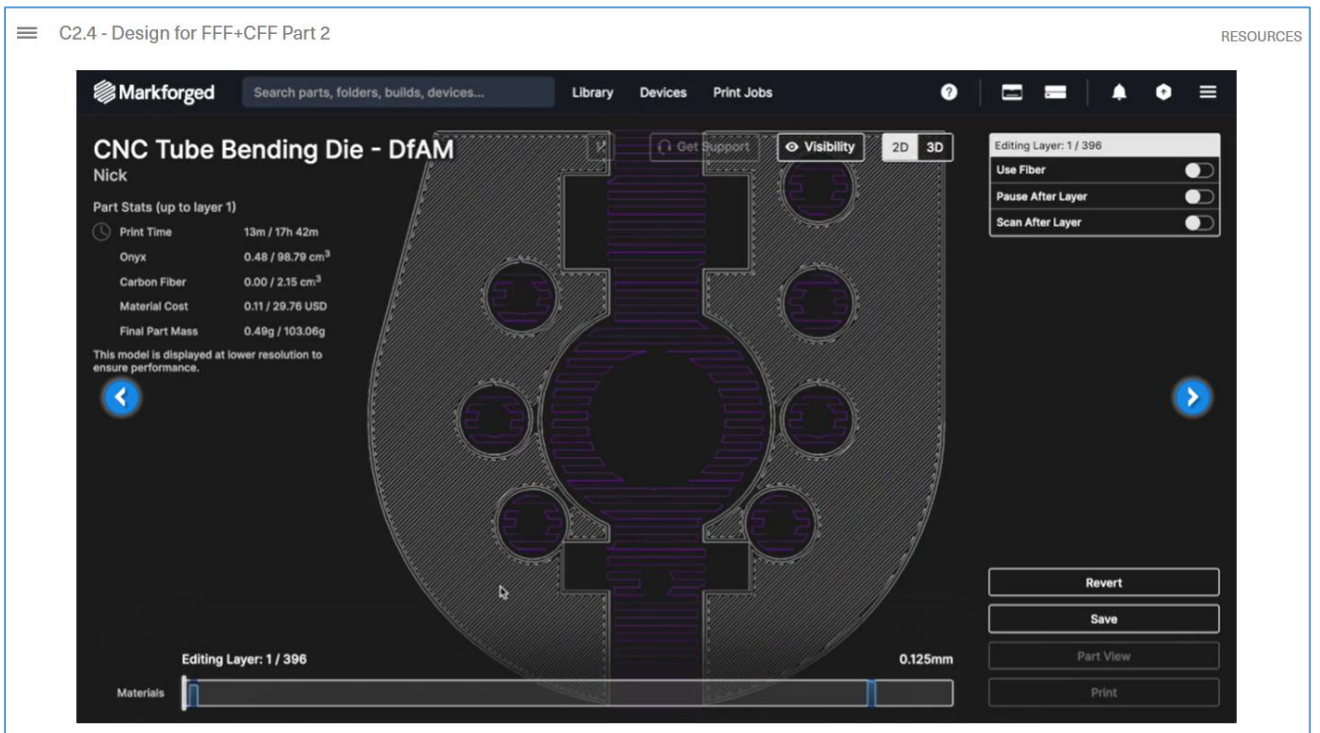


- Toggle Fiber on and create a Group.





- Right arrow: Reinforcement like a washer, but simply built in the part.

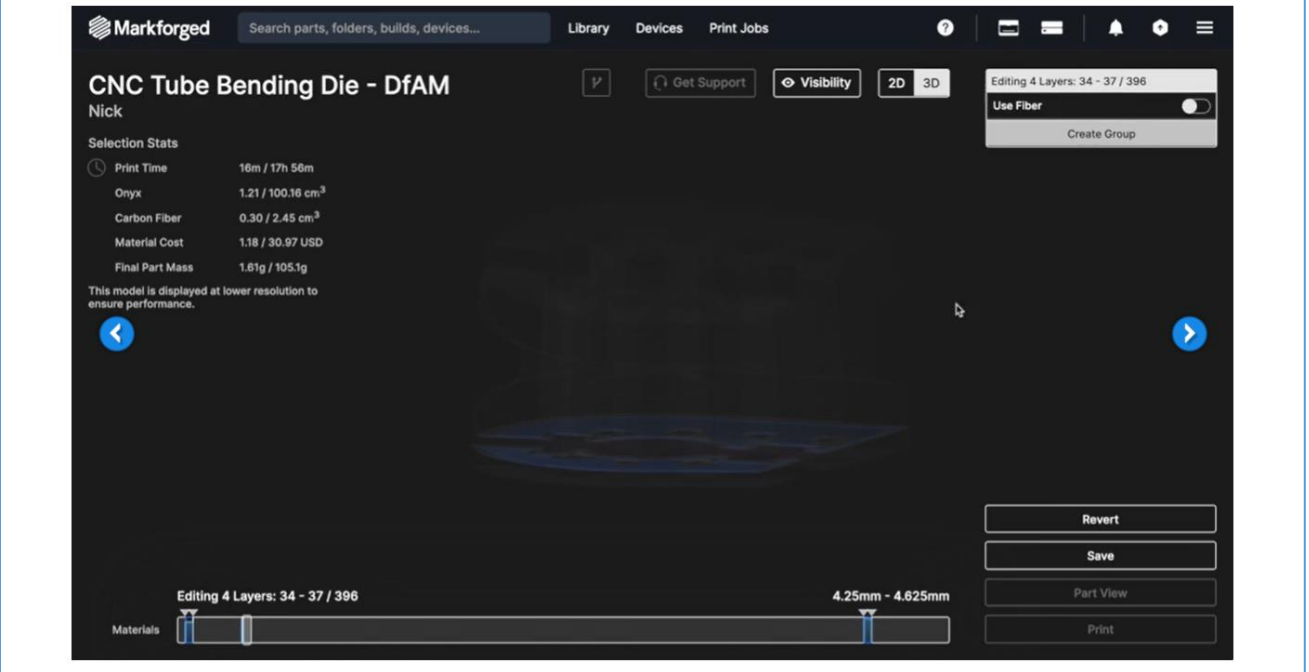


- 2D View > Look for the layer beneath the counter bore.





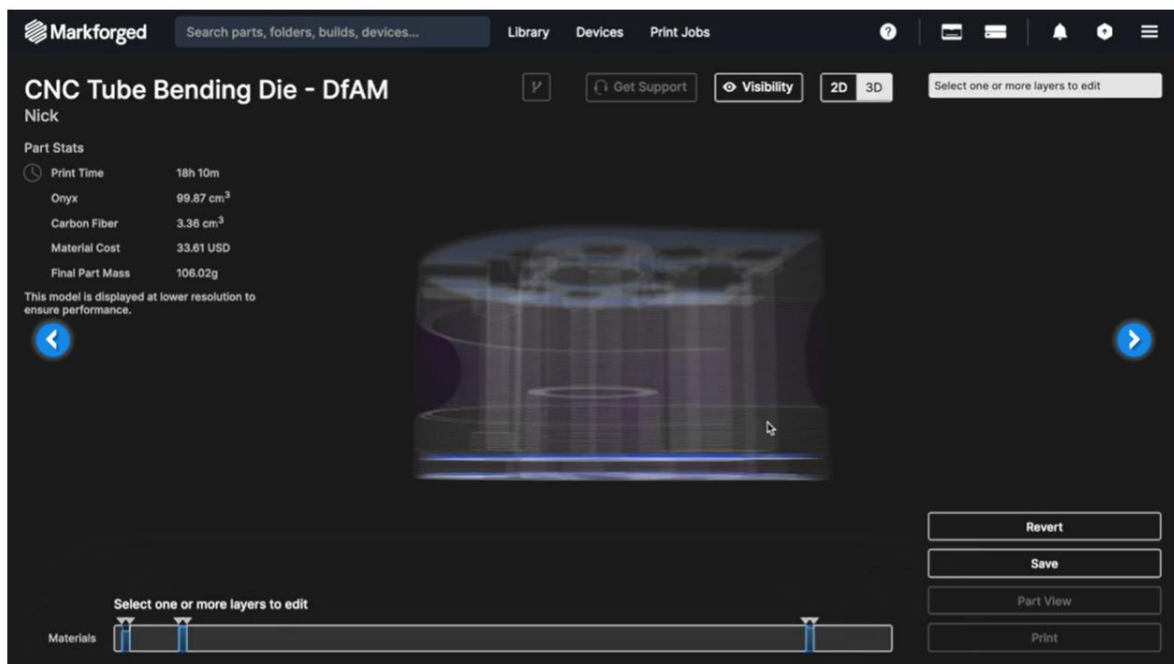
- Toggle Fiber on and go back in the 3D view



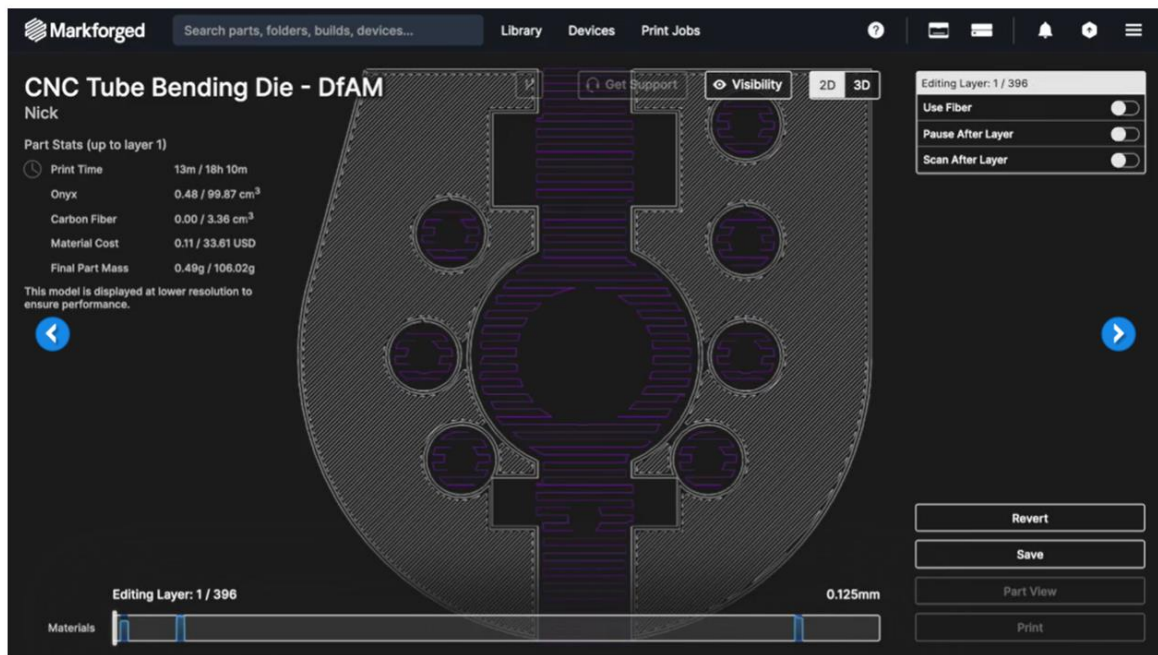
- In Layer slider and slide 4 layers



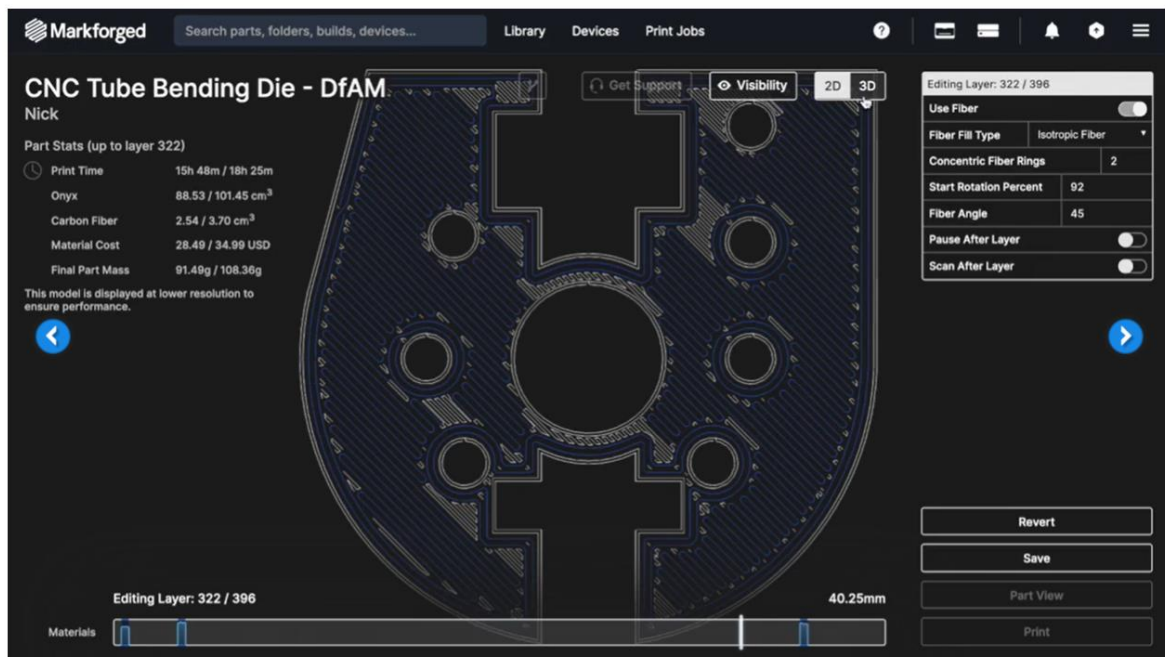
- And create the Group.



- Next we have to do the same thing underneath the nuts.



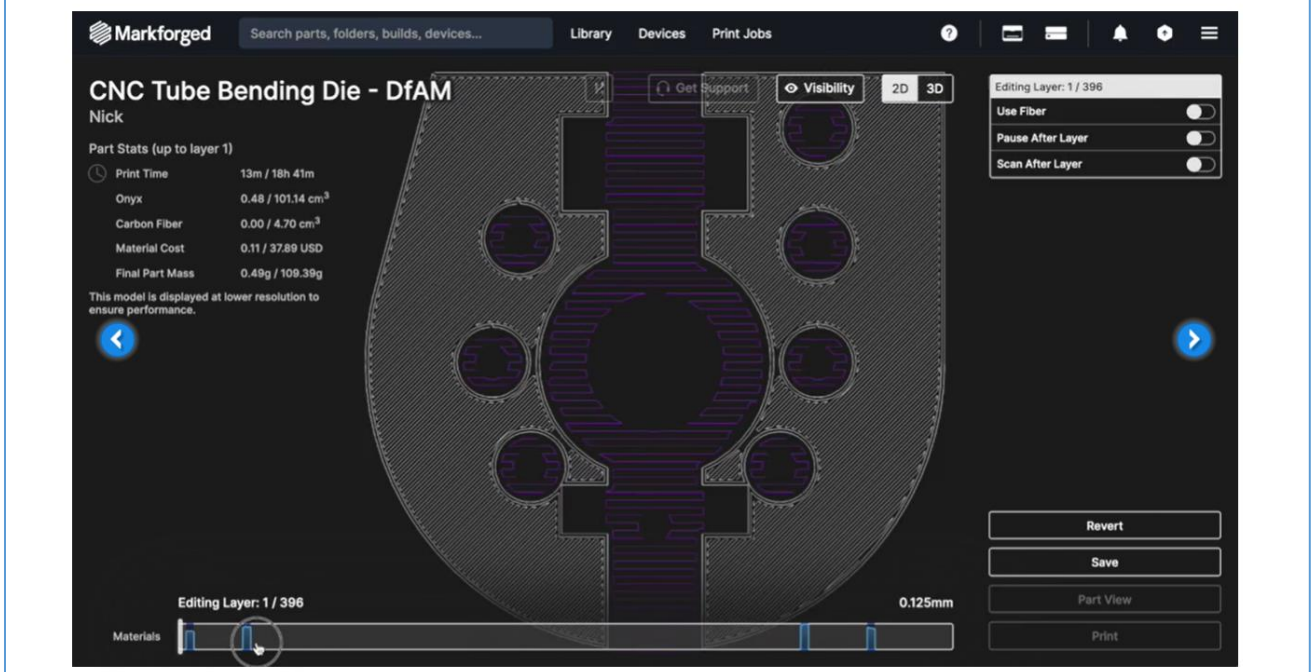
- Once again: Go into the 2D View.
- Drag the Layer Slider till you arrive at the first layer below roofing floor underneath the pockets for the captive nuts.



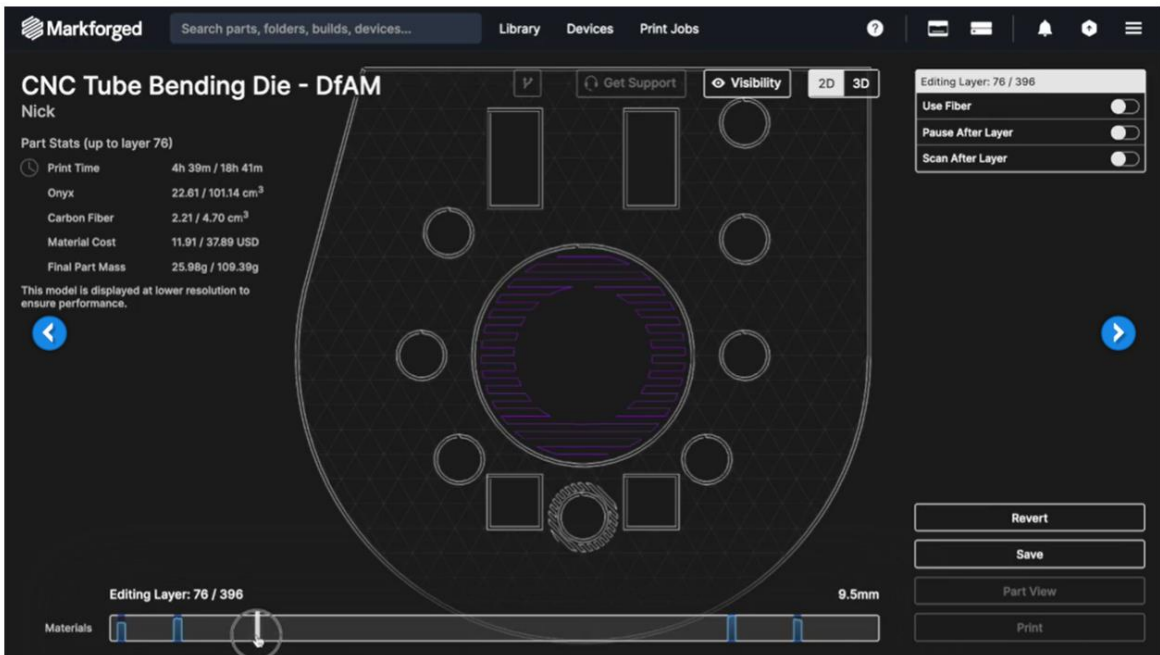
- Layer 322 and go back to the 3D View.



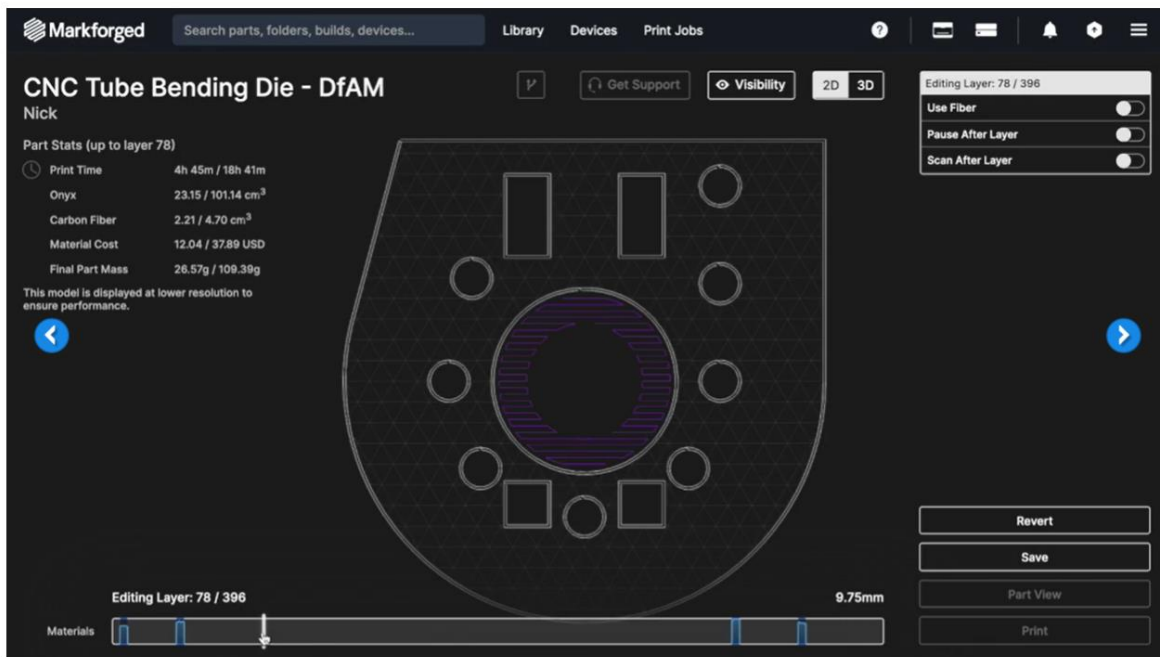
- Drag the slider 4 layers.
- Toggle Fiber on and Create a Group.



- Go back to the 2D View.



- Look for the roofing floor.

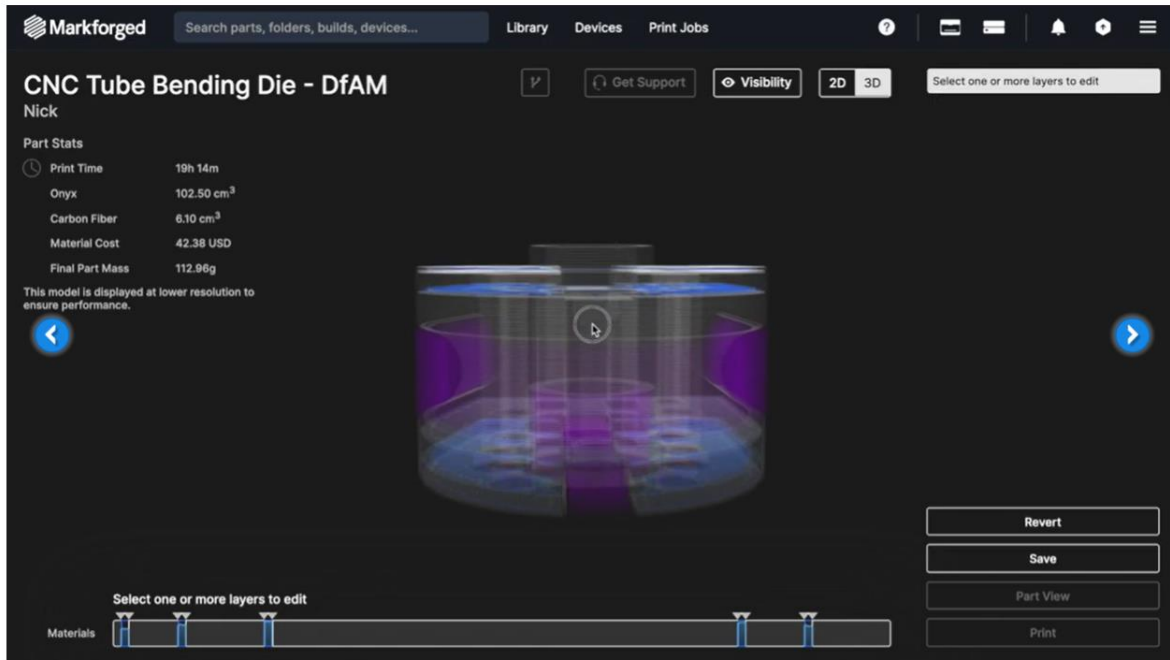


- To Layer 78 and toggle the Fiber on and go back to the 3D View.



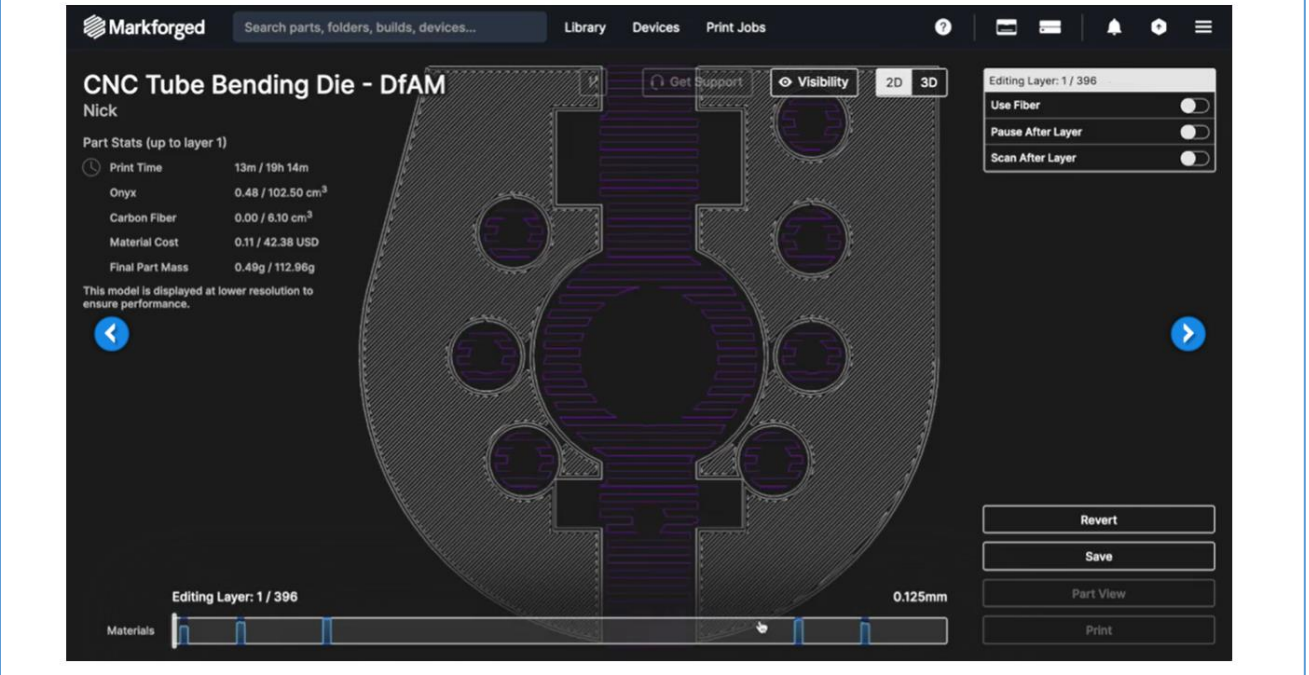


- Select Layer 78 to 81.
- Toggle Fiber on and Create the Group.



- Now the same thing for the top of the nut.

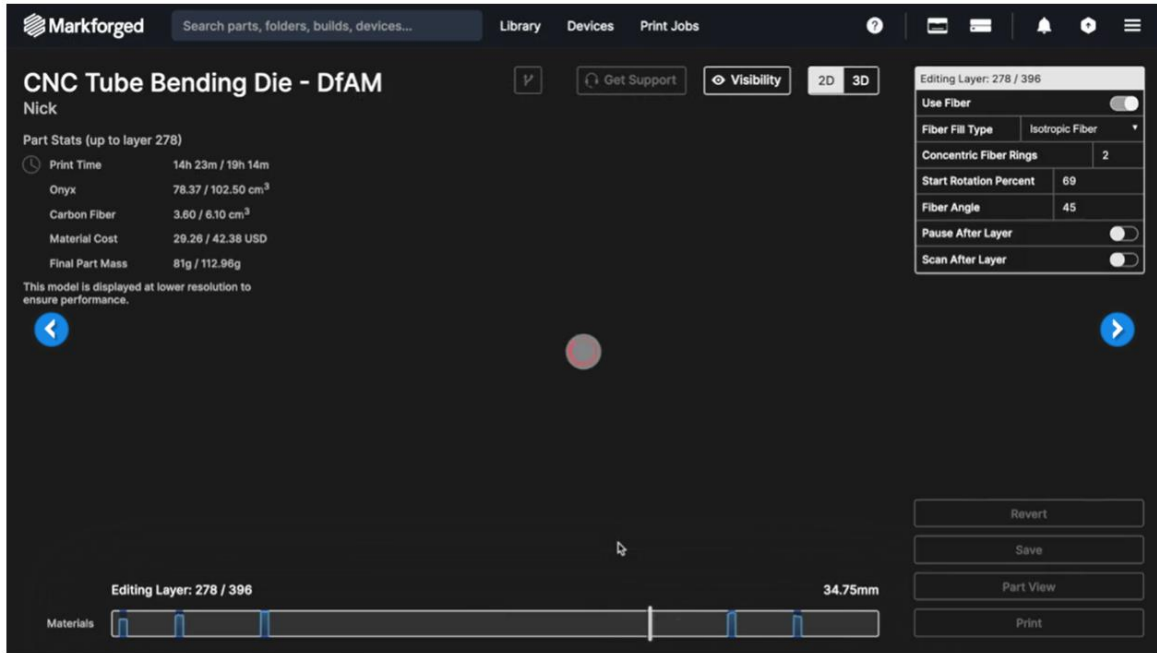




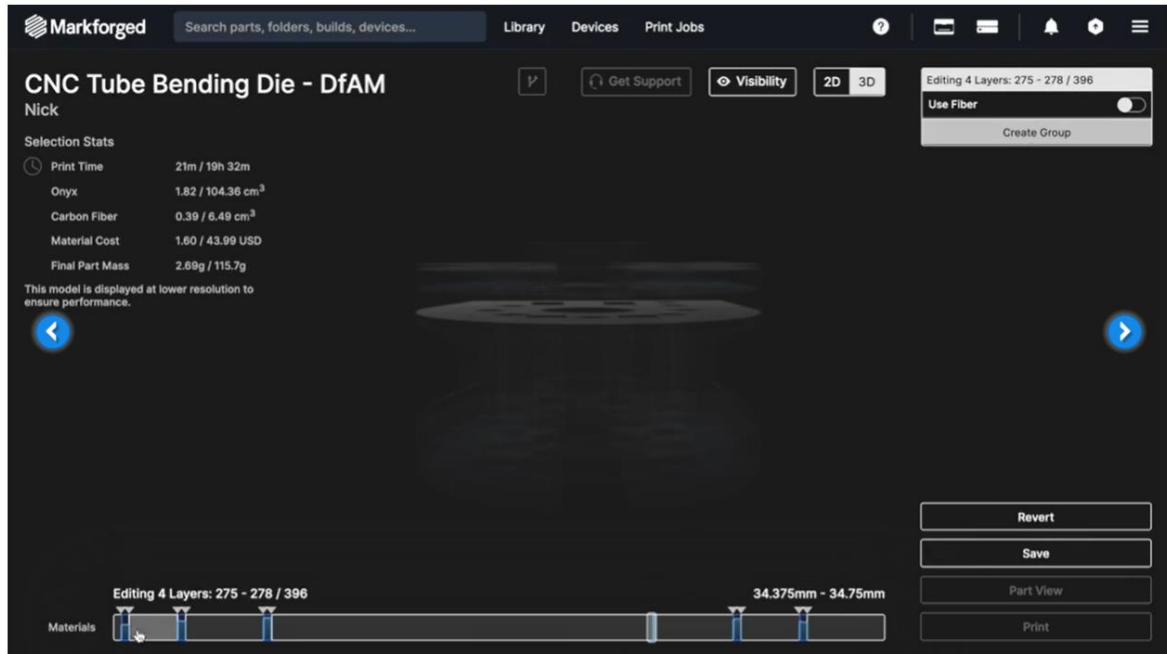
- Go back to the 2D View



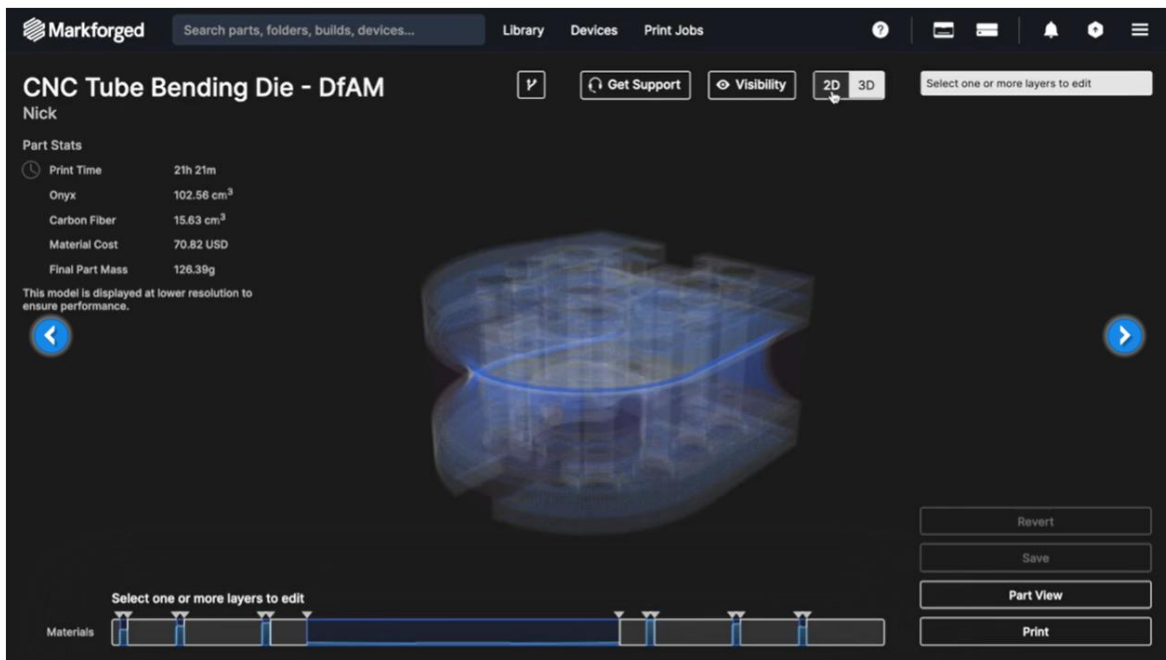
- and navigate to the layer I want.



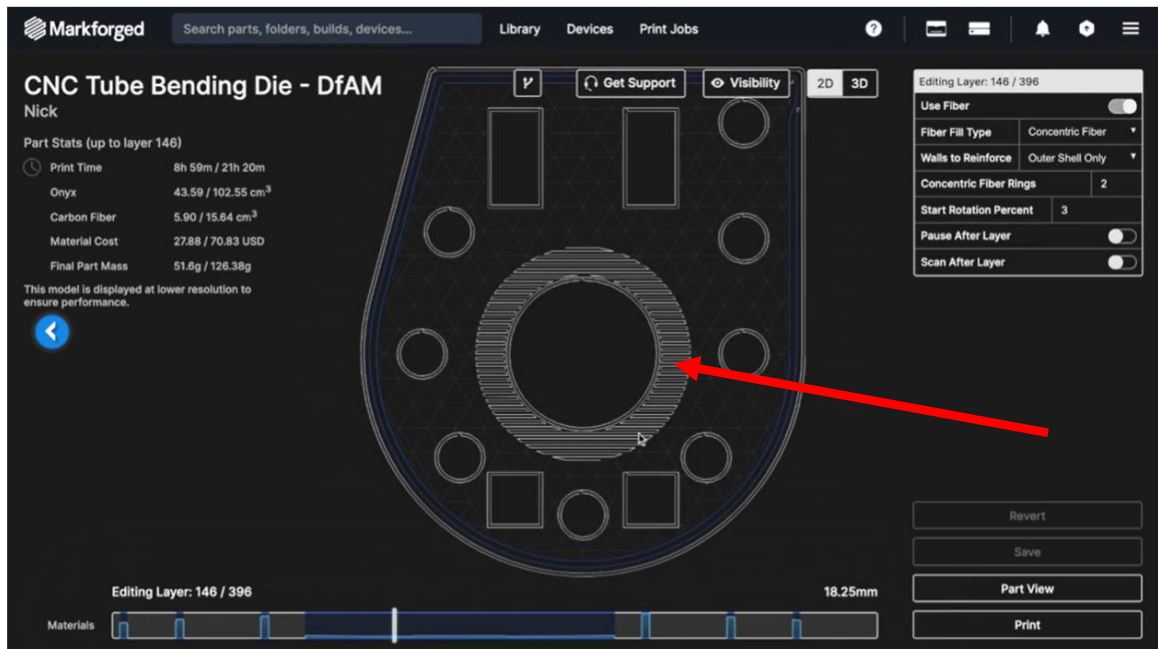
- Layer 78.
- Toggle Fiber on and go back to 3D View.



- Drag 4 layers with the slider.
- And create a group.
- Now, we fully reinforced underneath all the bolts and the nuts in this part a distribute out the compressive force to the bolts.



- Second right arrow:
  - Creating reinforcement for bolts due to compression force in the bolt/nut-holes. (in stead of using washers?) by laying a fiber layer beneath the bolthead, to help to distribute the bolt force.



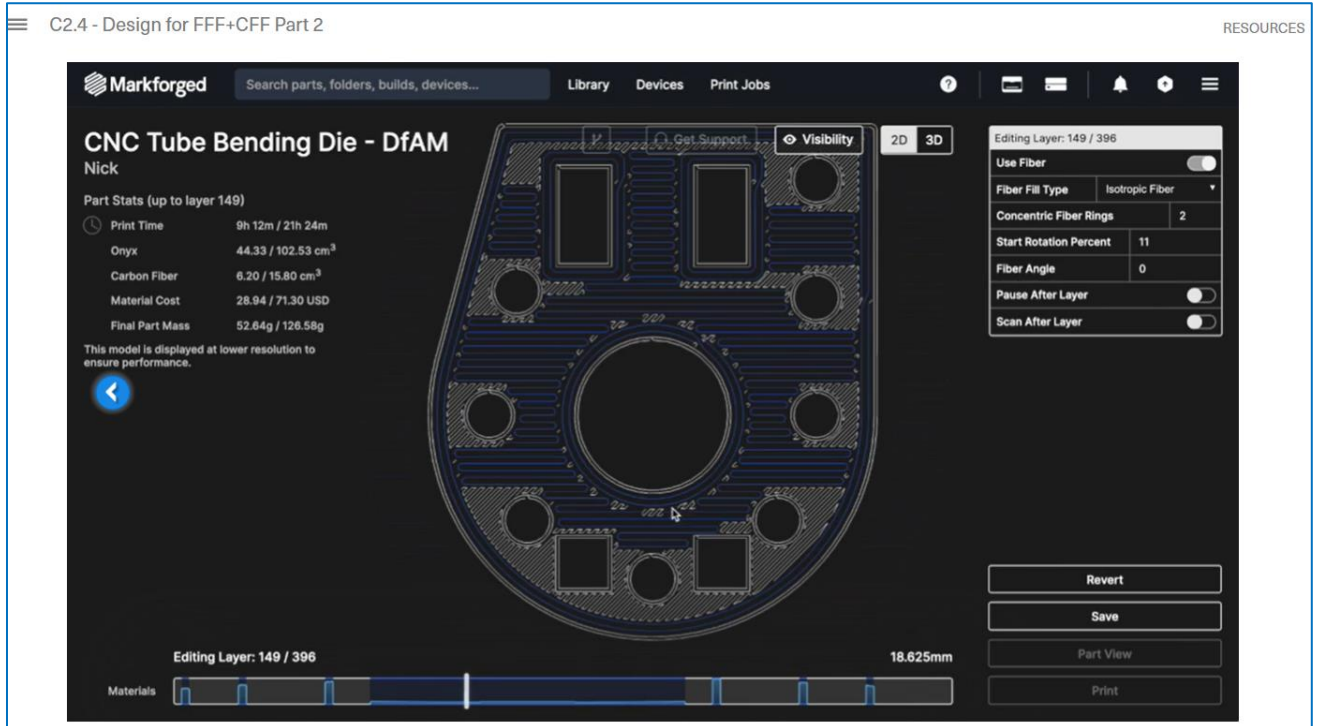
- Go to 2D and navigate to the floor layer beneath the counterbore.
  - Layer 146.



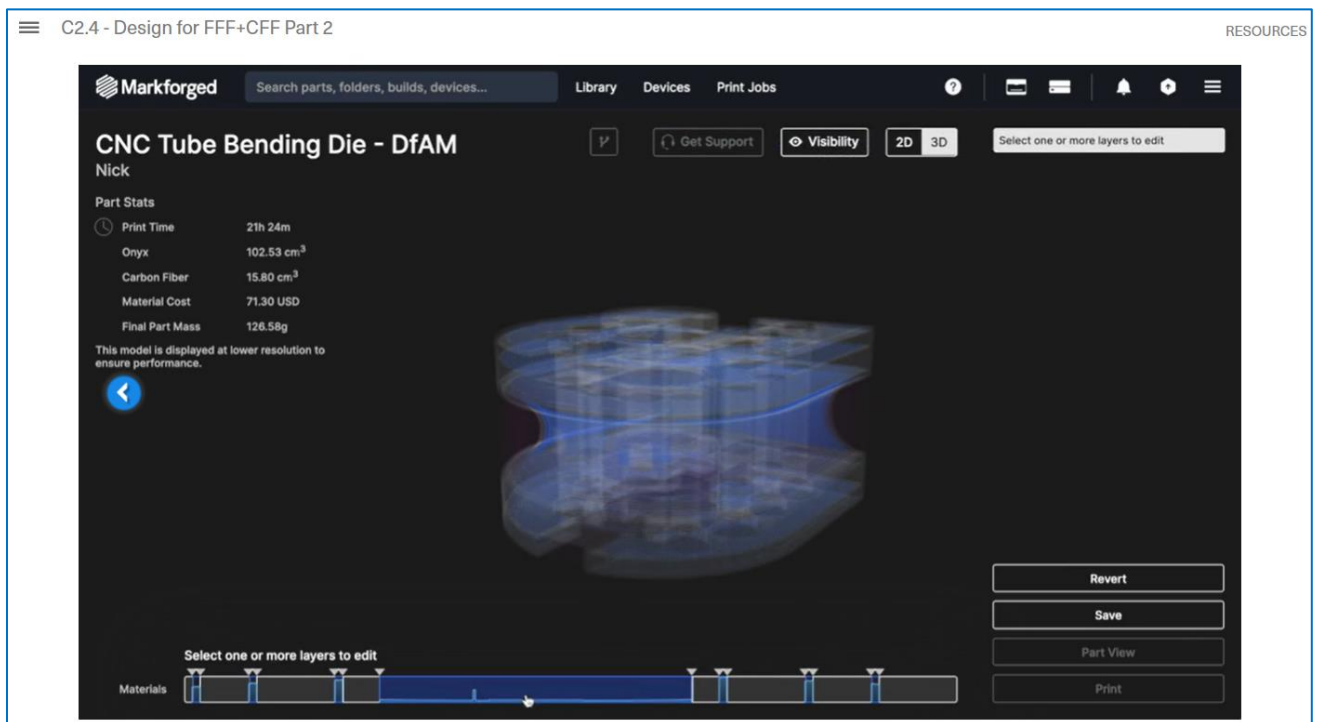
- Layer 149 is the first layer beneath the boltlayer.



- Change the fiber type into Isotropic fiber.



- Not an ideal scenario: Lot of cavities have not fiber.



- Go back to the 3D-view.



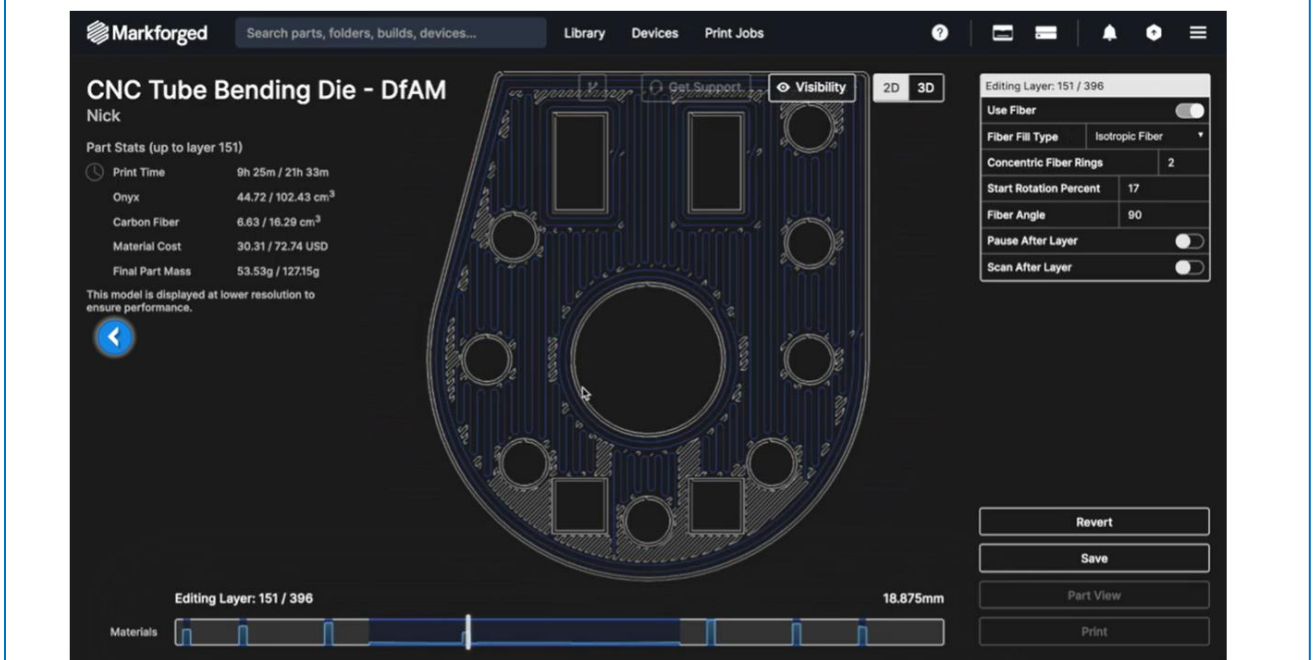


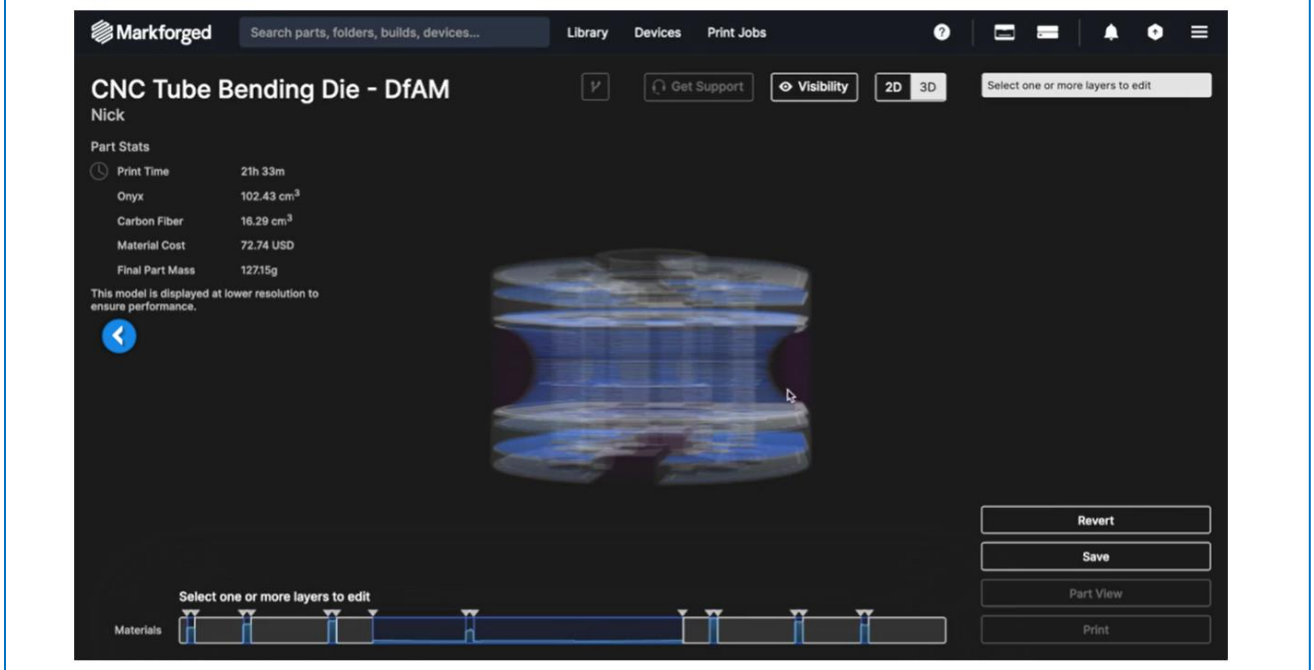
- Start at layer 149 and move upwards to make 4 layers.
- Fiber layer on Isotropic Fiber.
- Update the fiber fill type and create the group.



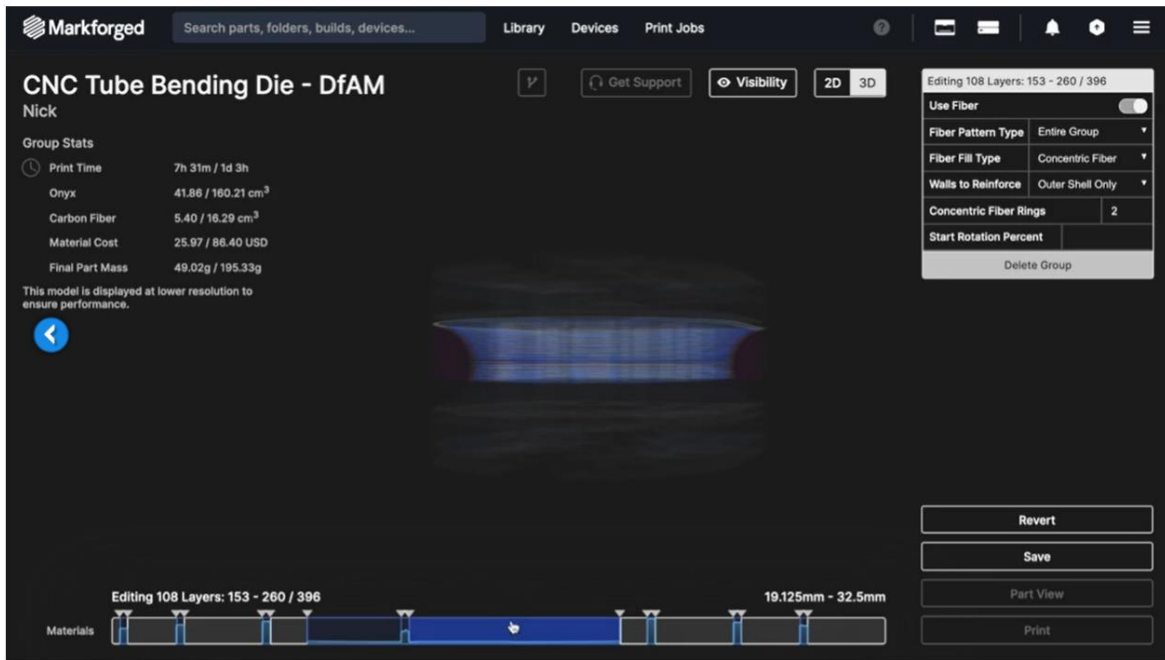
- Go back to the 2D-view and notice the different layers in following images.



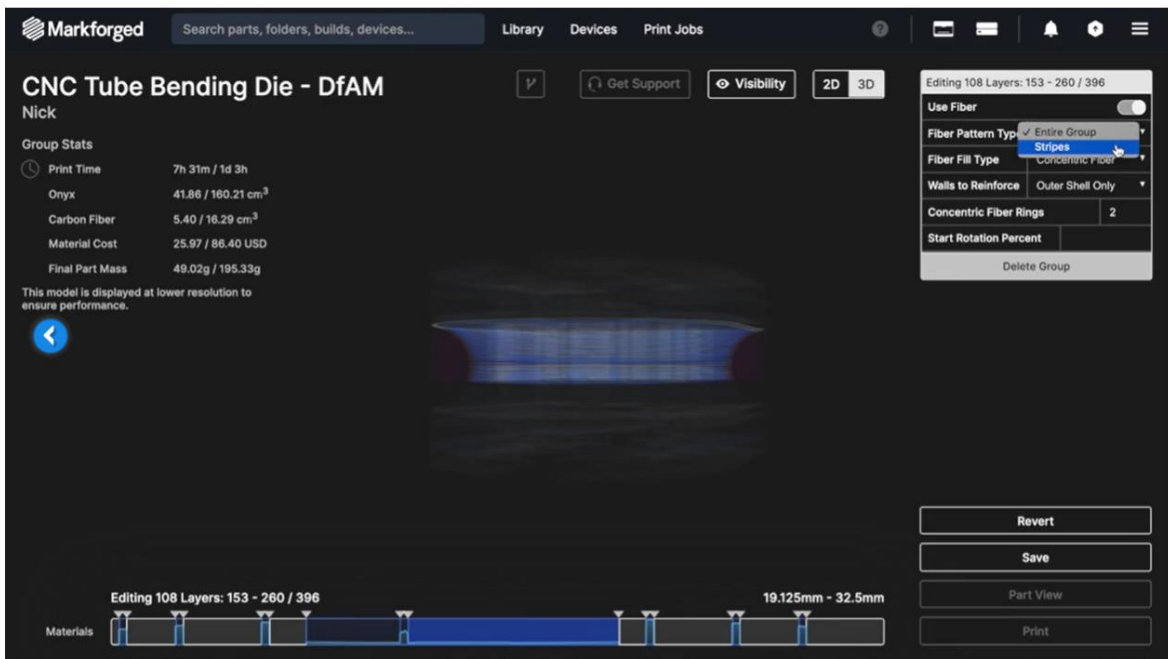




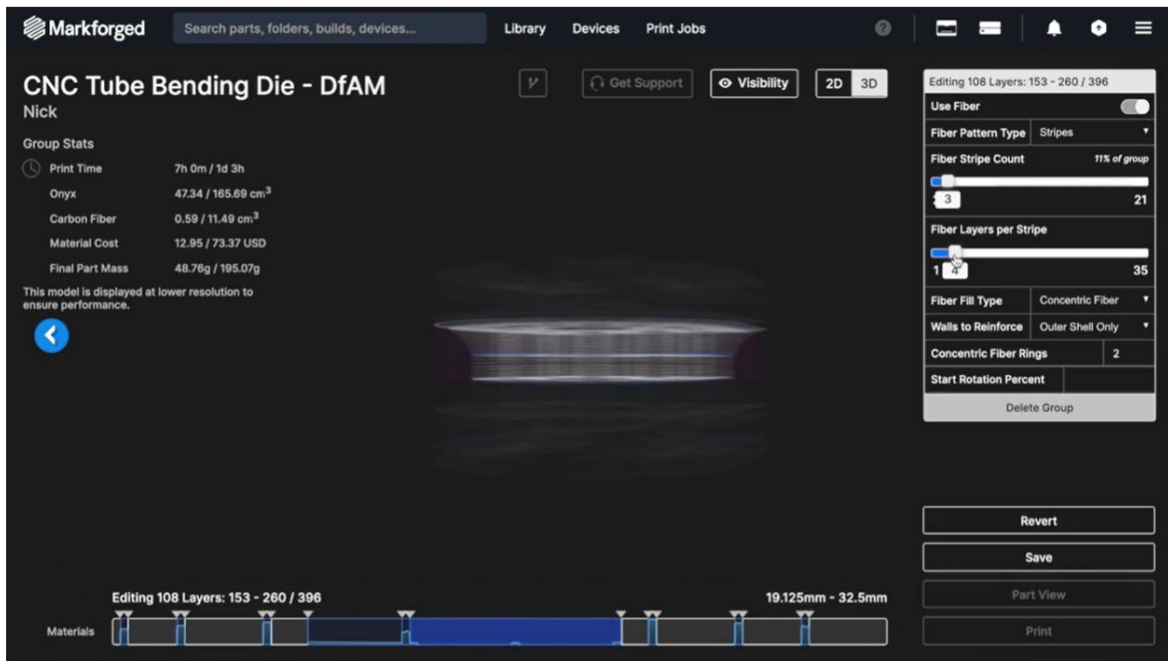
- The profile of the bend die.



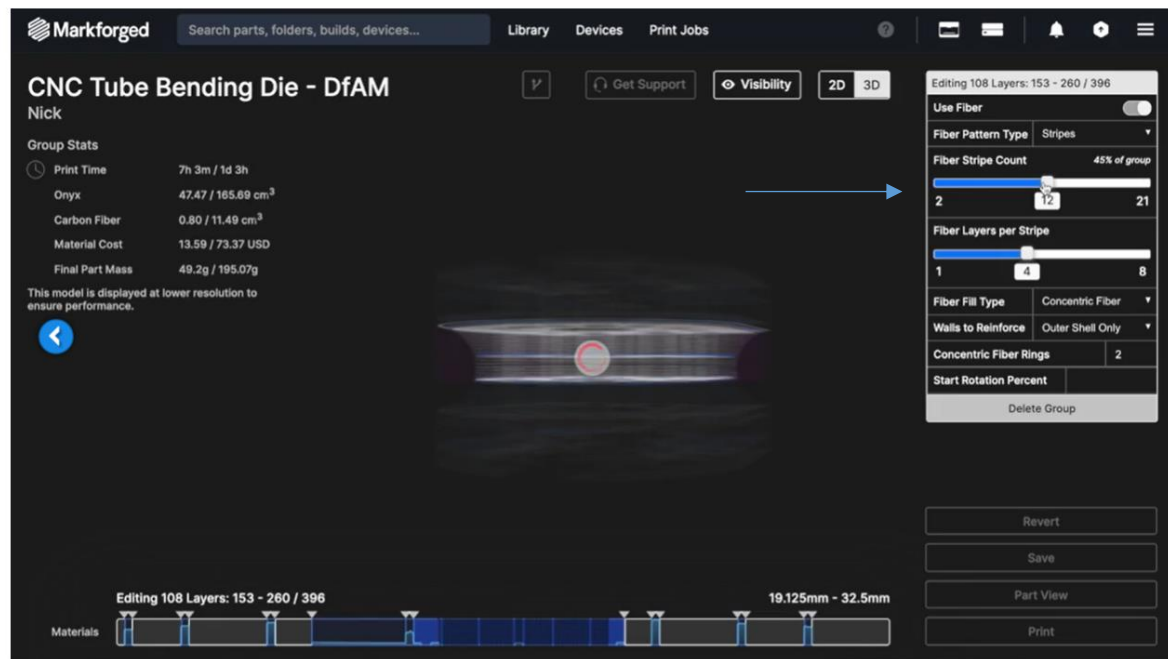
- Choose the layer groups in the bend path.



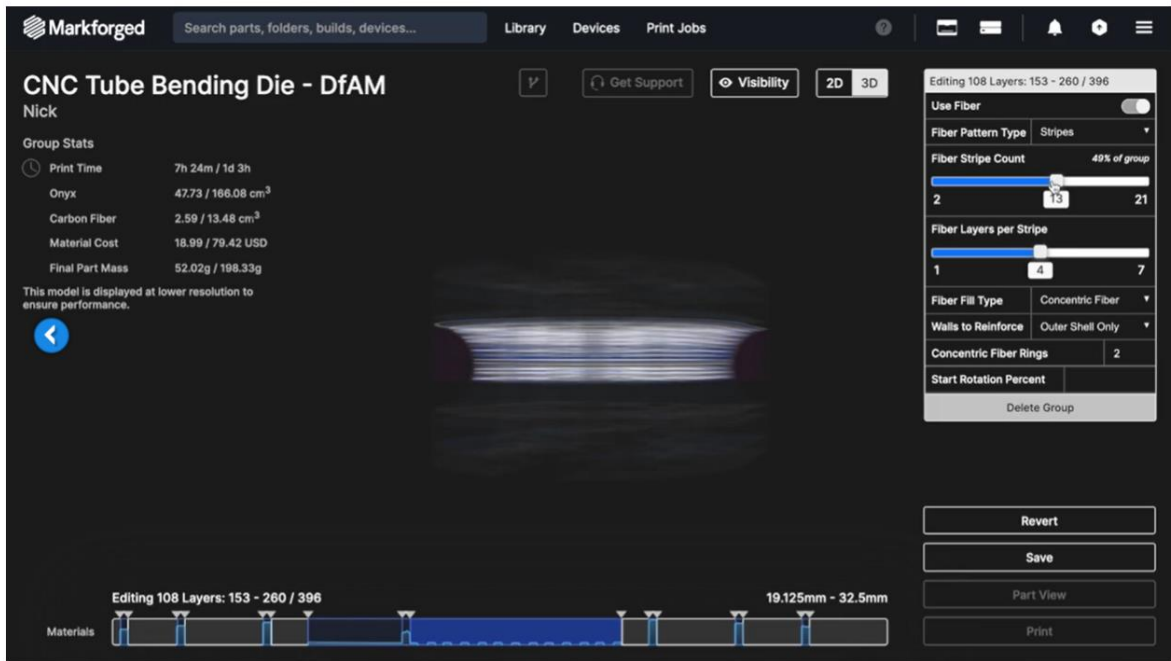
- Change the Fiber Type in Stripes.



- Adjust Fiber Layer per Stripe.



- Adjusting the slider

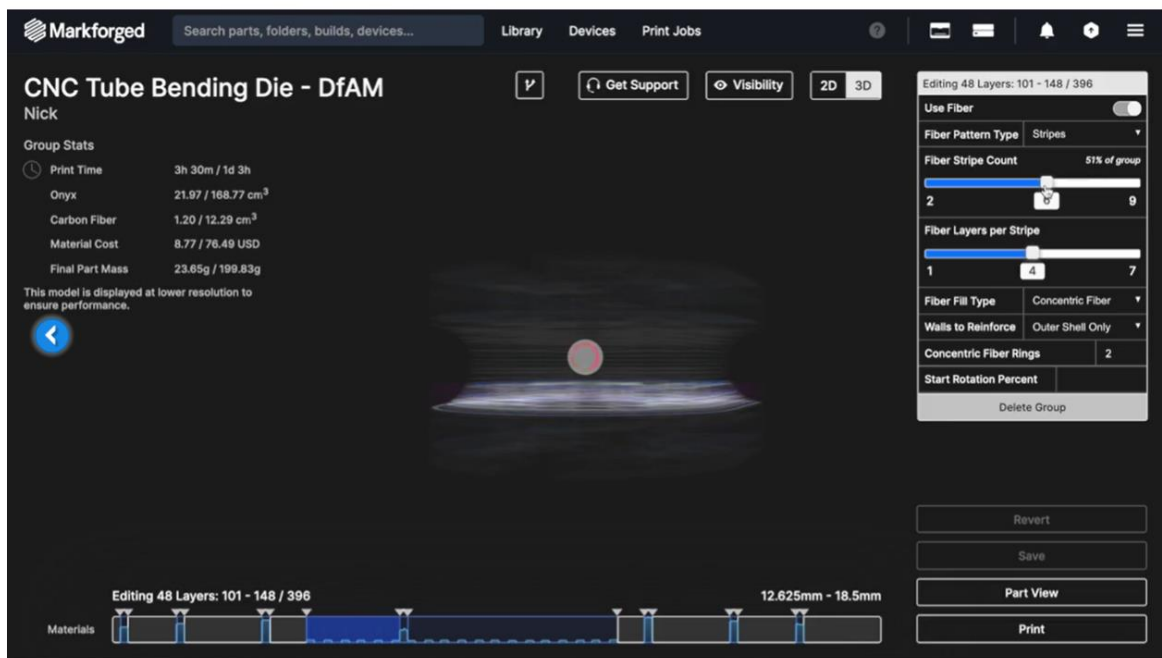


- To 13 Stripes.



- The lower group and change its pattern type into stripes as well.





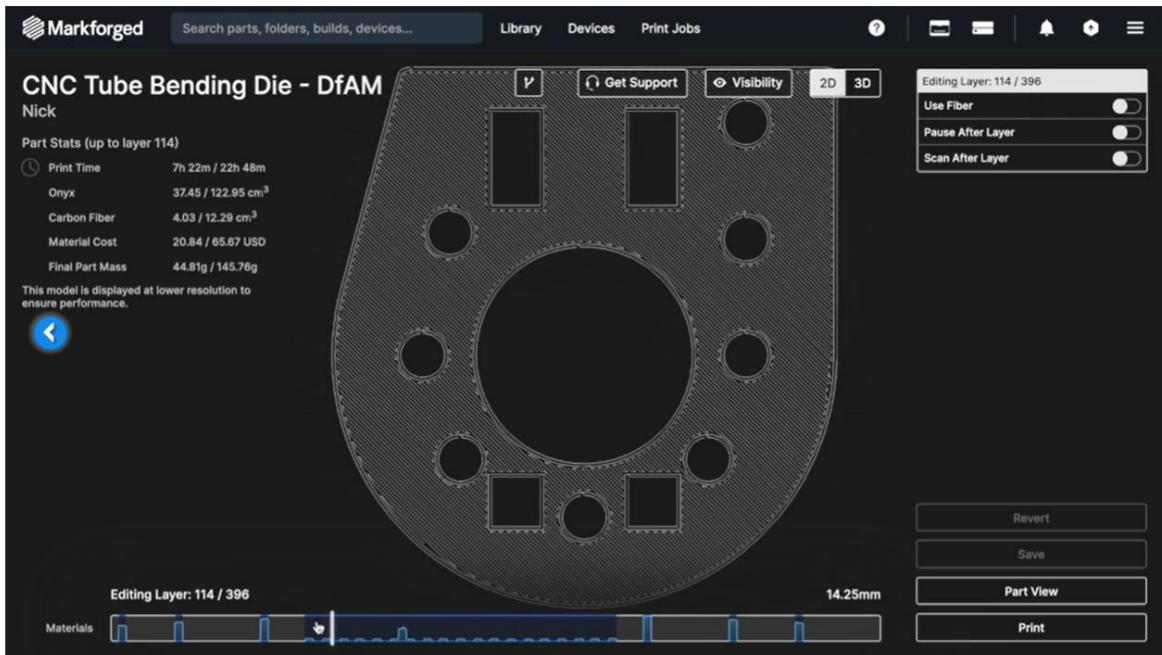
- Fiber layer per Stripe: 4 and Fiber Stripes Count: 6



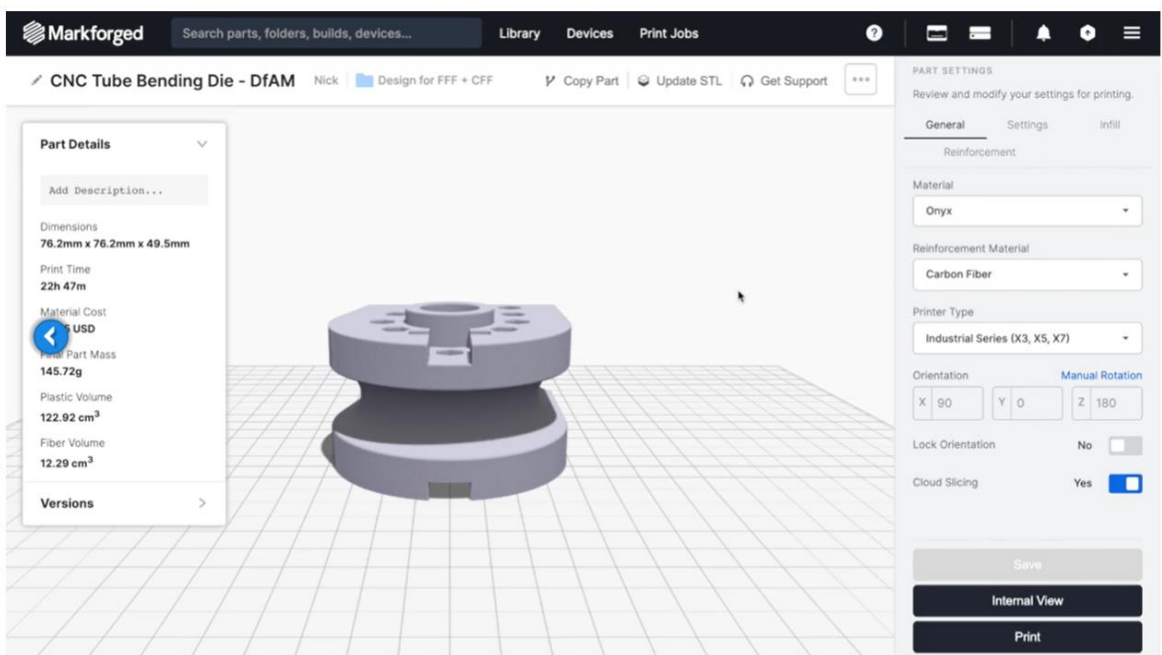
- Go back to 2D-view how it looks to move the slider through the layers. See next.



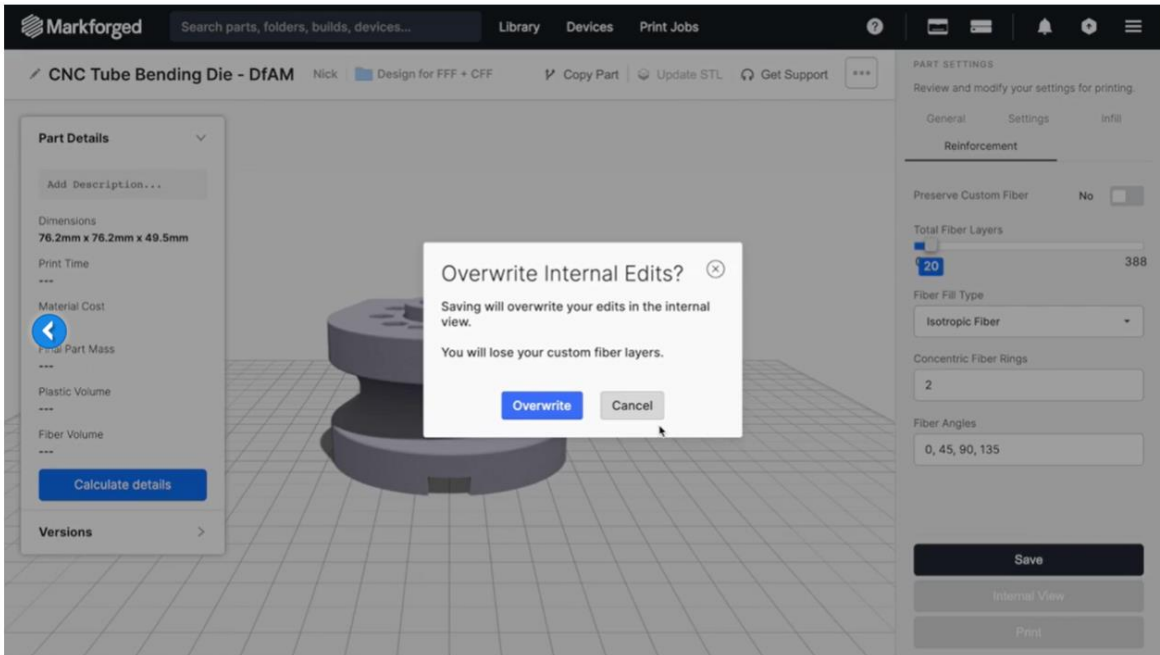




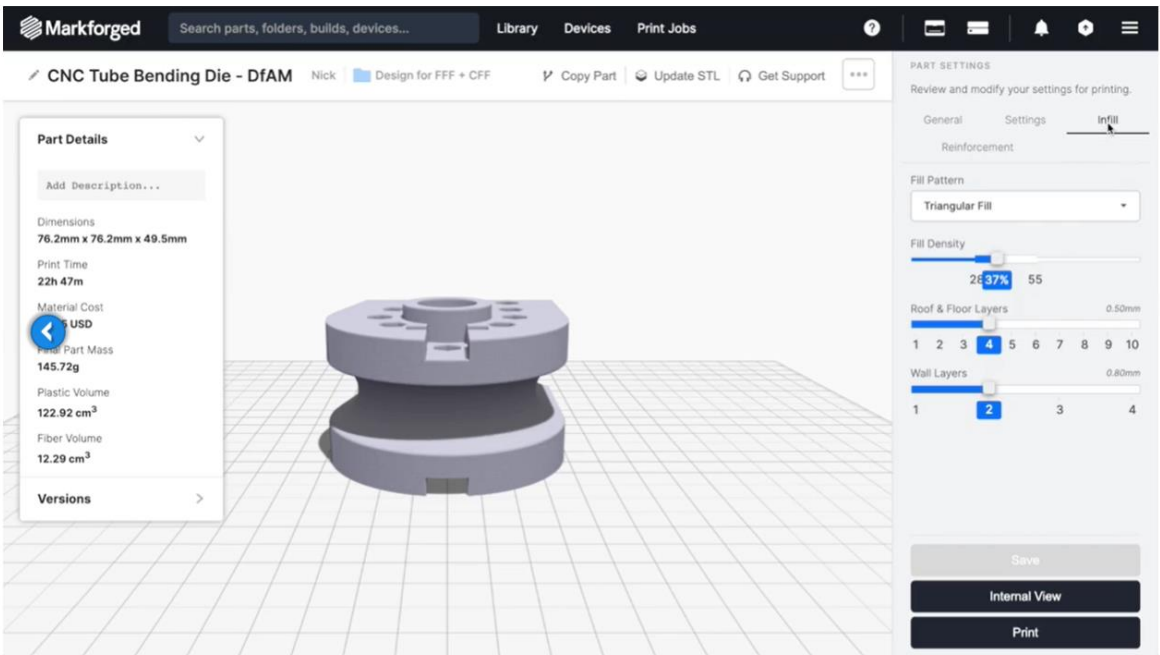
- Sections of solid roofs and floor layers.
- Save your work.



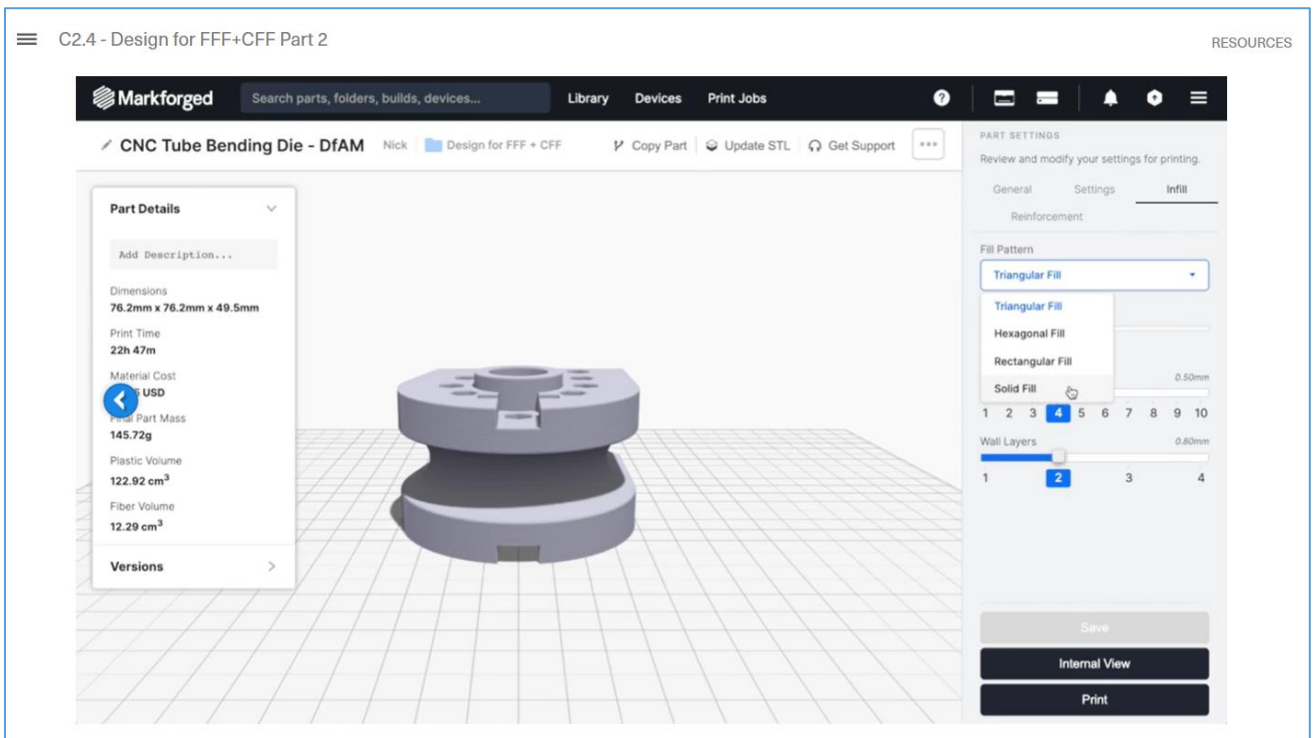
- Change infill pattern from rectangular to completely solid.



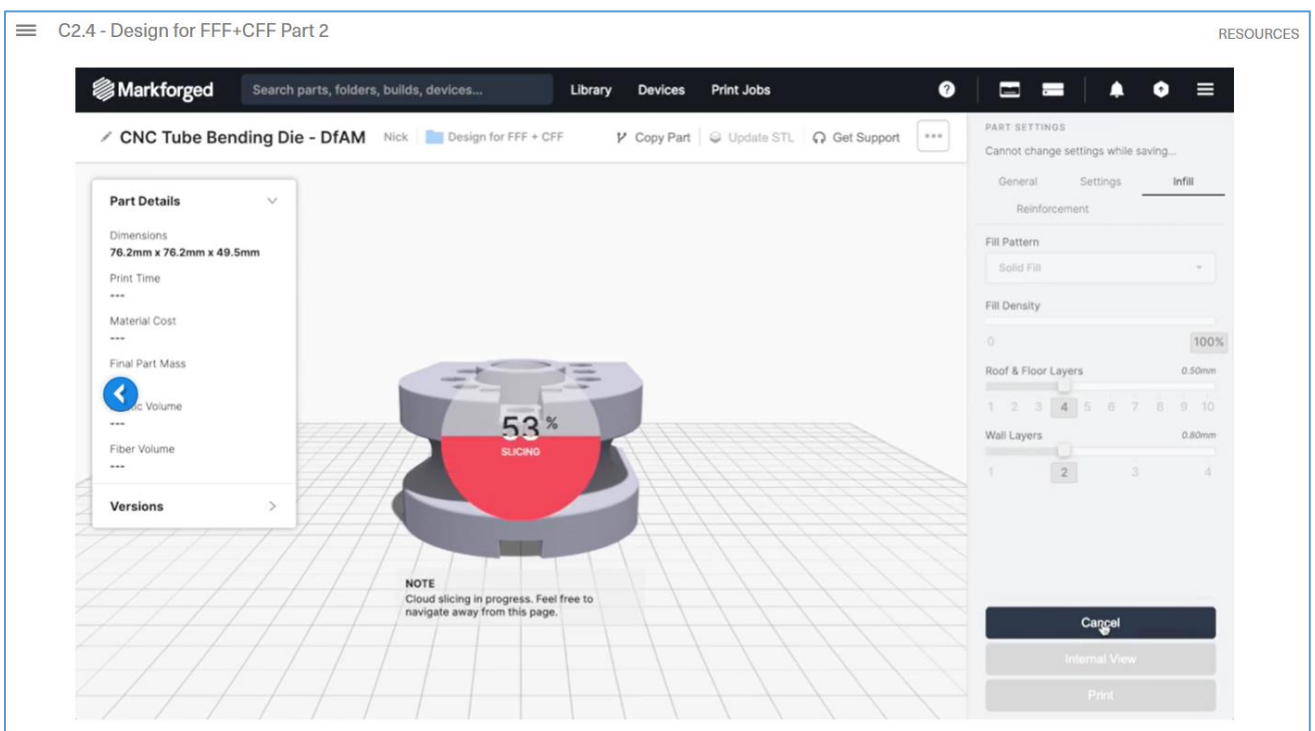
- We won't change the fiber configuration.



- Go to the Infill tab.

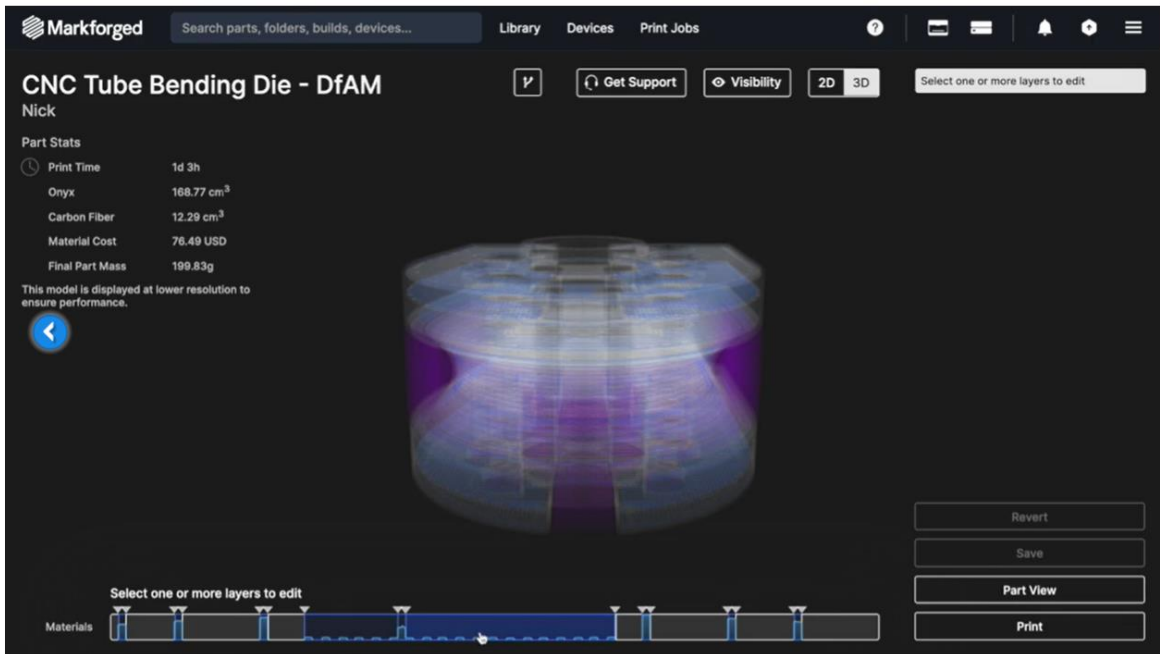


- Solid Fill.

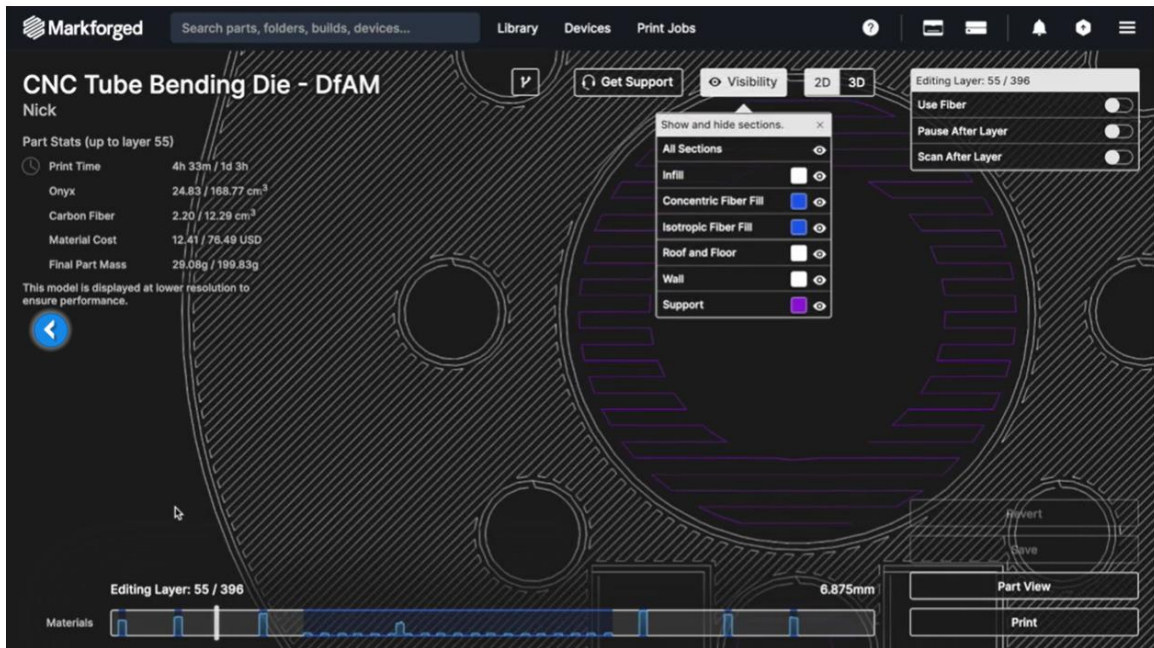


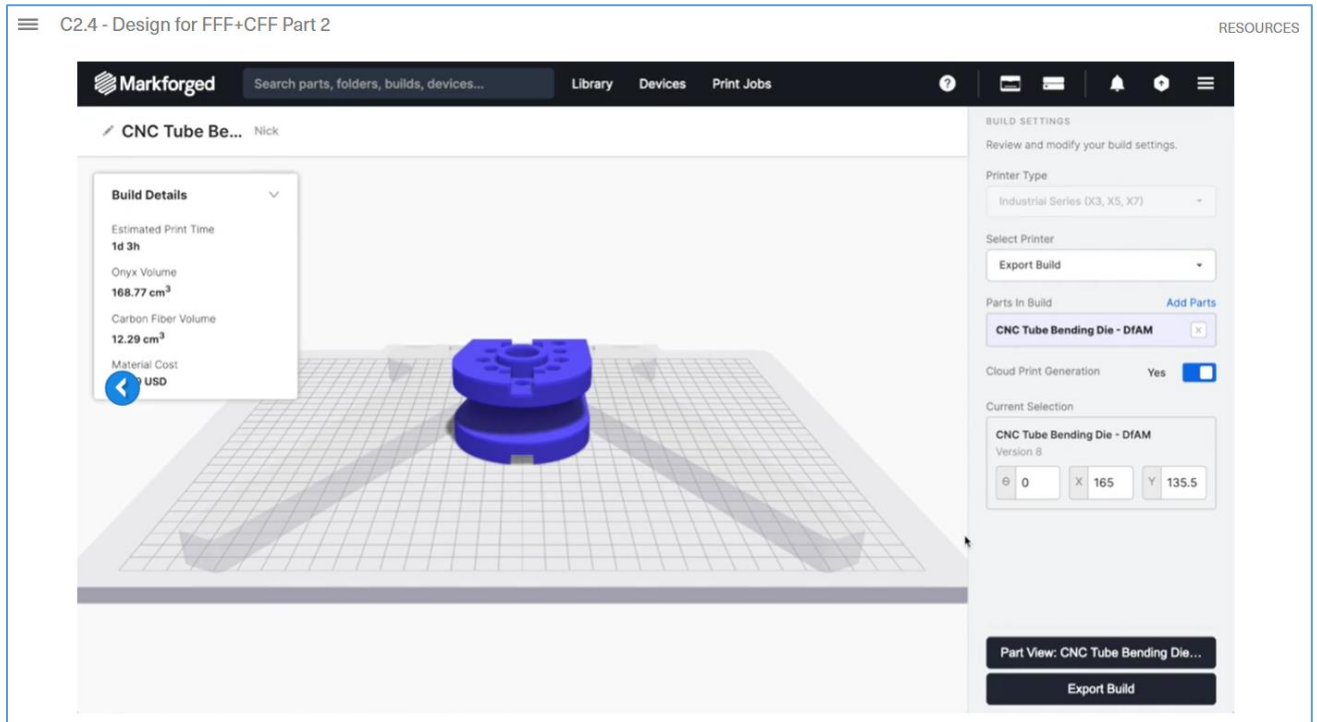
- This time no warning. The plastic infill type didn't change the fiber configuration.
- We can save our work, without worry.





- Notice that all our fiber layer groups are preserved (beschermd).





- The first print of a complex modified reinforced product.



- **Finished Bending Die**

- With the bolts, nuts and the machine keys.
- Lowering the costs and faster DfAM will give you advantage.



## Problem → Part Workflow

1. Identify **core functionality**
2. First pass **design/block CAD**
3. **Revise design** to meet core functionality
4. Import into **Eiger**
5. First pass **print settings** and material **selection**
6. **Print and test**

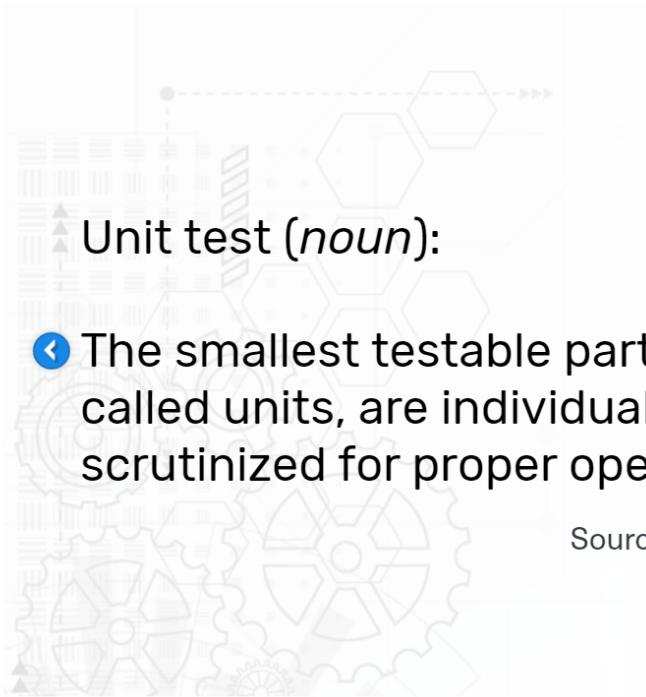


- **Step 6: Print and Test.**

A slide graphic with a light gray background. It features several interlocking gears of various sizes and colors (white, light blue, light green). A dashed line with an arrow points from the top left towards the right. The text "Iterate faster with unit testing" is centered in a bold, black font, with "unit testing" in orange. A blue circular arrow icon is on the right side. The Markforged University logo is in the bottom right corner.

Iterate faster with **unit testing**

- **Iterate faster with unit testing**



▲ Unit test (*noun*):

- ◀ The smallest testable parts of an application, called units, are individually and independently scrutinized for proper operation

Source: [Software Testing Fundamentals](#)

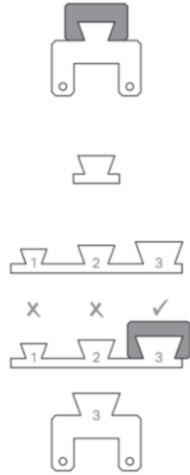


- Scrutinize = onderzoeken
- [Software Testing Fundamentals](#)



- **Demo: Unit Testing in Action**

## Unit Testing Workflow



1. Identify critical feature to test
2. Extrude-cut to smallest possible sub-section
3. Print a test piece with multiple configurations
4. Rapidly test iterations
5. Roll results back into larger model and print

- **Unit Testing Workflow**

## Problem → Part Workflow

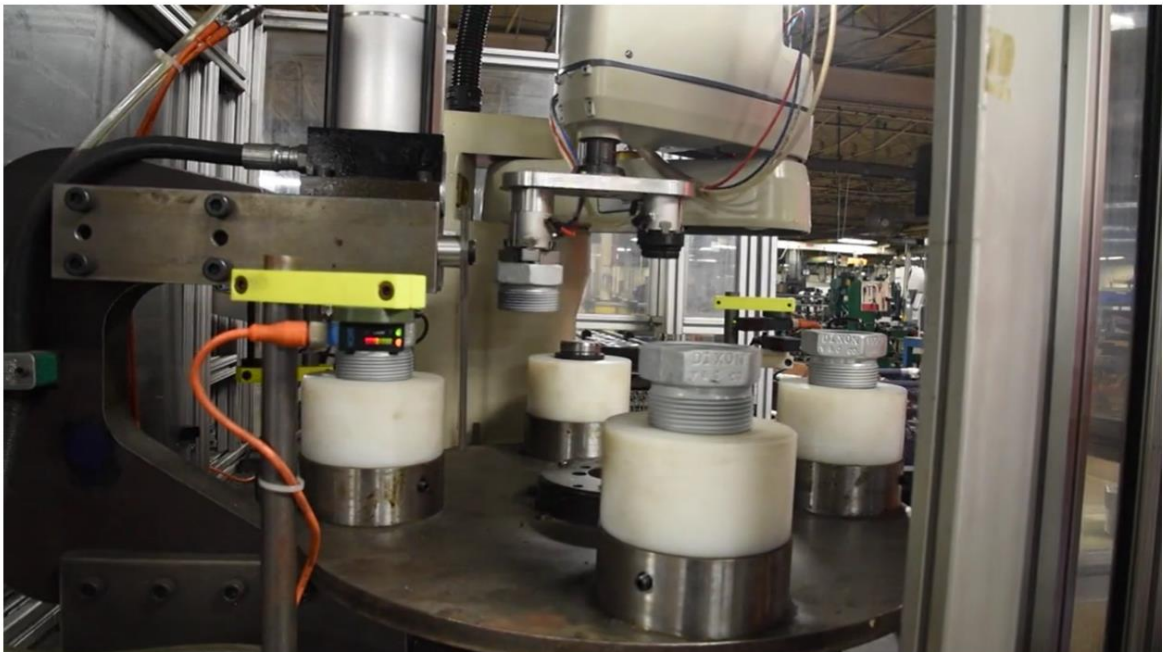
1. Identify **core functionality**
2. First pass **design/block CAD**
- 3. Revise design** to meet core functionality
4. Import into **Eiger**
5. First pass **print settings** and material **selection**
- 6. Print and test**

- **Recap: Problem to Part Workflow**



## DFAM Case Study: End-of-arm Tooling

- **DFAM Case Study: End-of-arm-Tooling**



- **Video: Automated Assembly Work Cell**

## Challenges in Automation

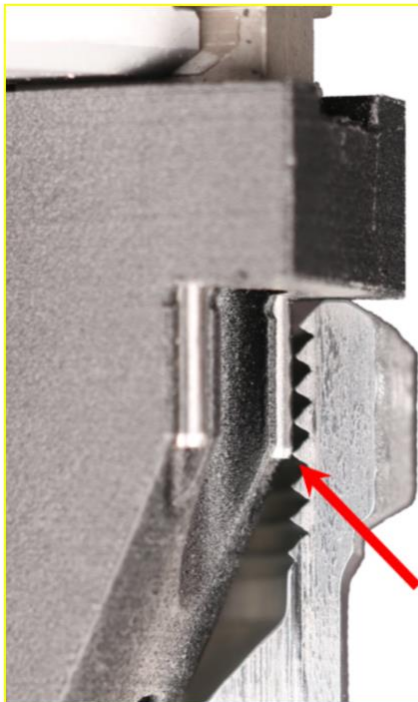
3 jaw gripper had high wear from threaded ID

~1 month PM schedule too short

**Challenge:** extend jaw life and retain fast iteration



- Challenges in Automation



## An Off-the-Shelf Solution

**Solution:** press fit steel dowel pins at contact surface

3D printing = easy design complexity, fast iteration

Steel pins resist wear, extend jaw life

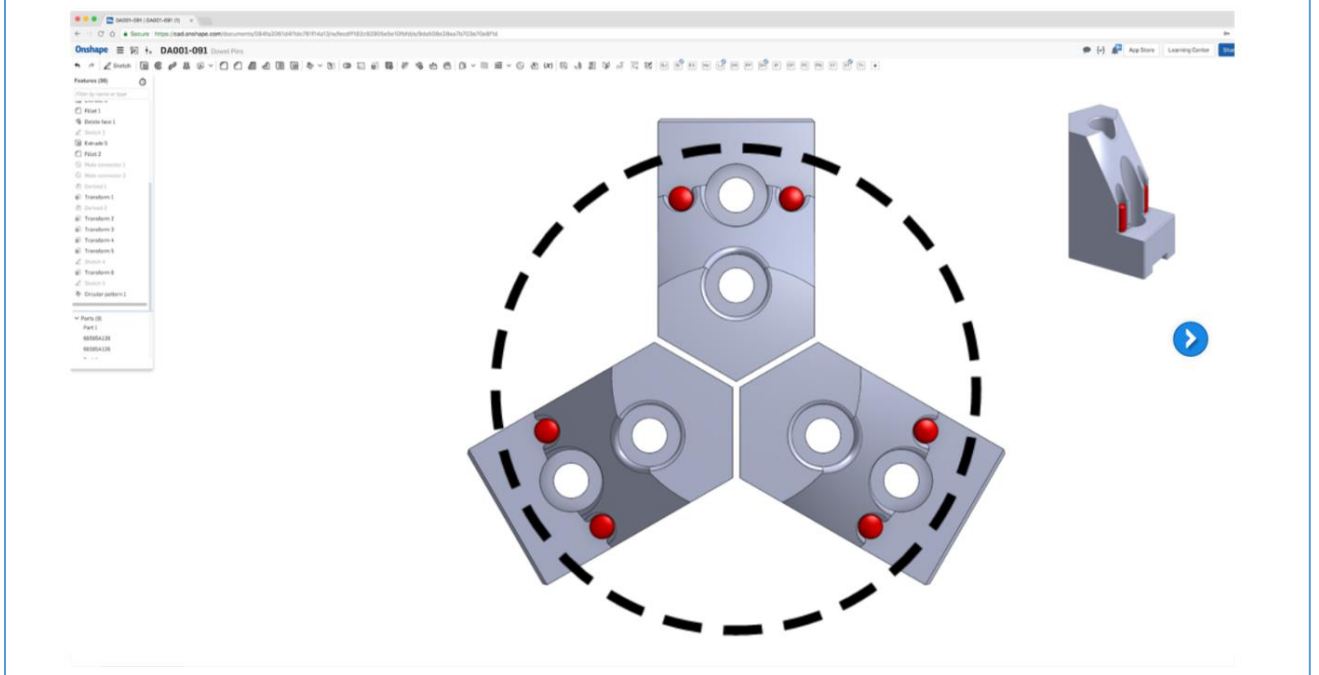
- An OTS Solution

What if the jaw pressure causes the pins to damage the ID threads?

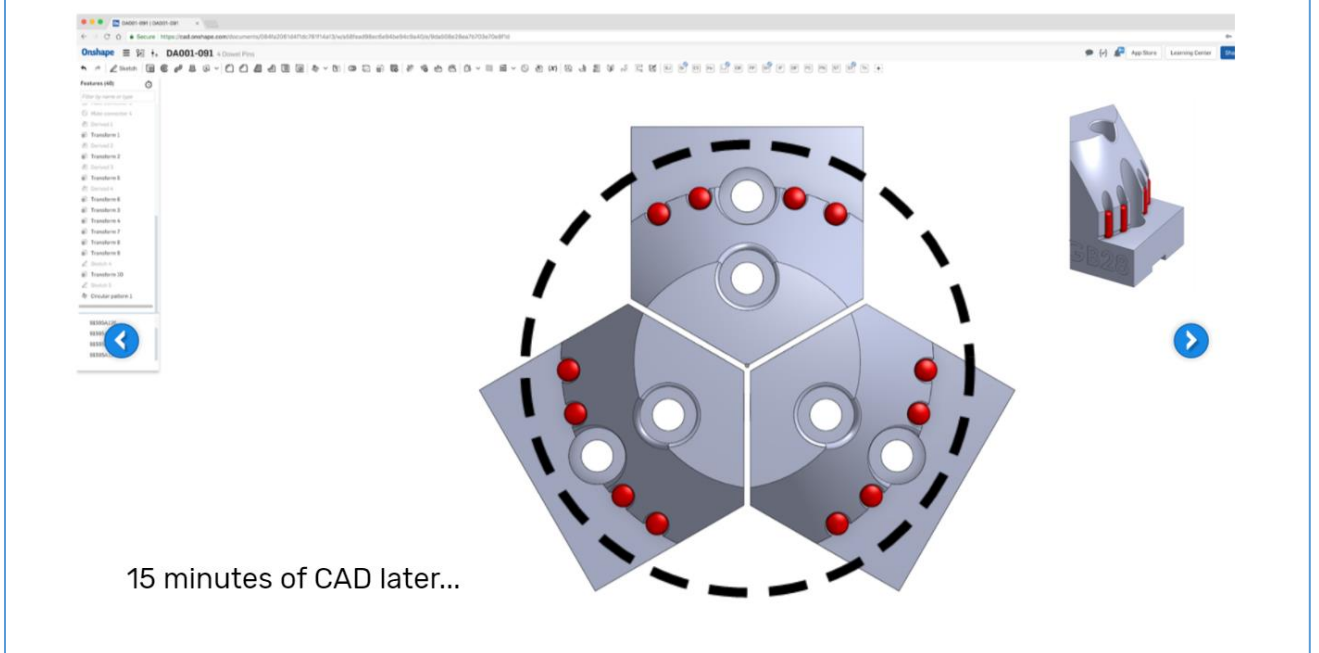
- **What if the jaw pressure causes the pins to damage the ID threads?**

3D printing offers us high geometric control and fast iteration cycles...

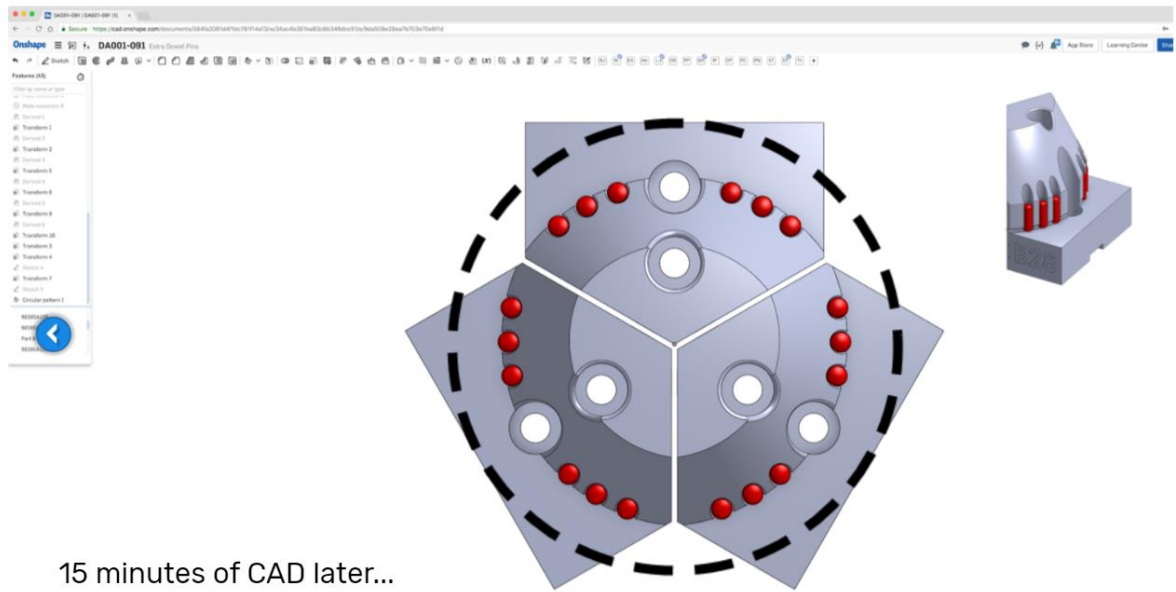




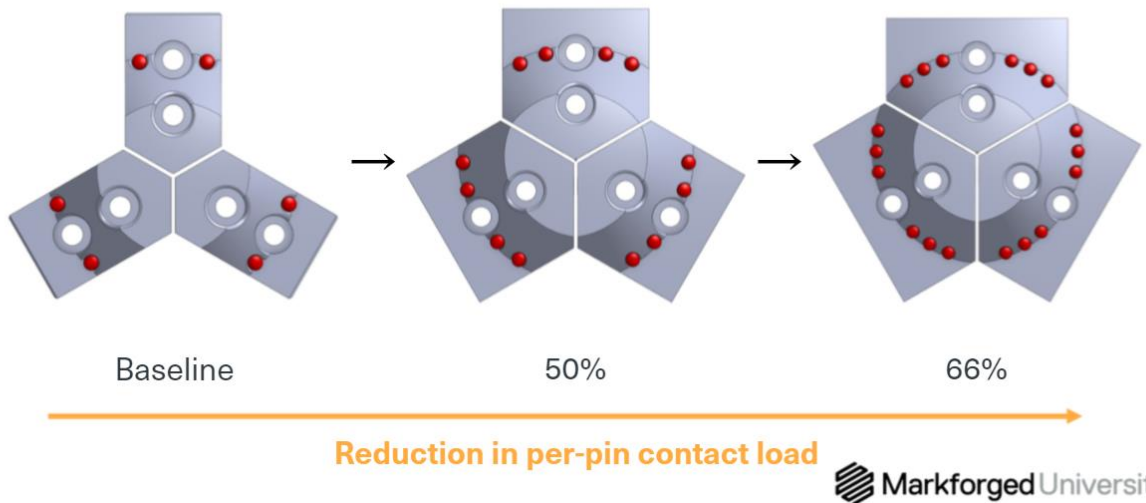
- Iterating for Functionality



15 minutes of CAD later...



### Rapid Design Iteration



- **Rapid Design Iteration**



- **Model Review**

Which of the following can add significantly higher than plastic strength to the Z-axis of a 3D printed part when oriented along the Z-axis?

- Bolts with a nut
- Solid Onyx infill
- Machine keys
- Carbon Fiber

Put the following steps in the Unit Testing Workflow in order

1.
2.
3.
4.
5.

Incorporating commercial off-the-shelf (COTS) components into your 3D printed parts is a useful design strategy because...

- They're often cheap and readily available
- They add properties and capabilities not available in 3D printed materials
- All of the above
- They can be quickly assembled into the printed part

## Results

Your Score: 100% (30 points)  
Passing Score: 80% (24 points)

### Result:

✓ Congratulations, you passed.

Finish Module

Review Quiz

## C2.5 – Opportunity Identification on the Manufacturing Floor



- **Opportunity Identification on the Manufacturing Floor**

## Module Overview

Key Takeaways

Your In-house Experts and Guides

Pain Points + Cost Drivers

Common Manufacturing Applications

Materials in Tooling & Fixtures

- **Model Overview**

GOAL:

Internalize strategies for identifying high-value opportunities in manufacturing environments that can be addressed with high strength 3D printing

- **Module Goal**

- Internalize = eigen maken.



## Key Takeaways

**Challenge** your assumptions about what problems 3DP can solve

**Discover** opportunities via search strategies

Identify new aspects of value to add to your **ROI**

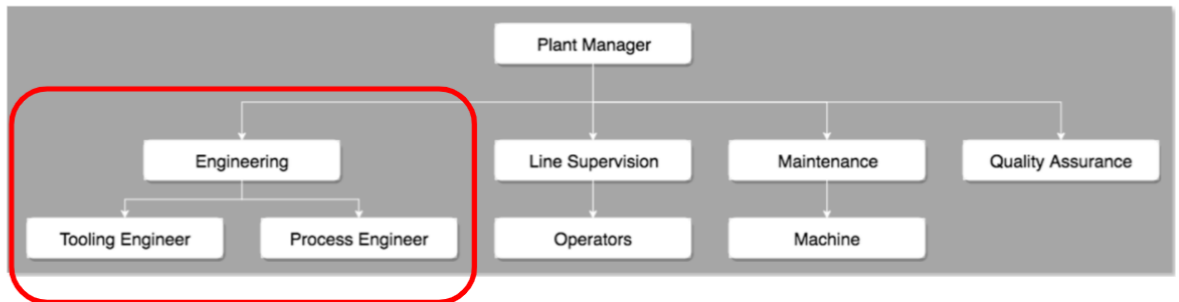
- **Key Takeaways**

- Belangrijkste leerpunten.

**“Who should I ask for help?”**

- **“Who should I ask for help?”**

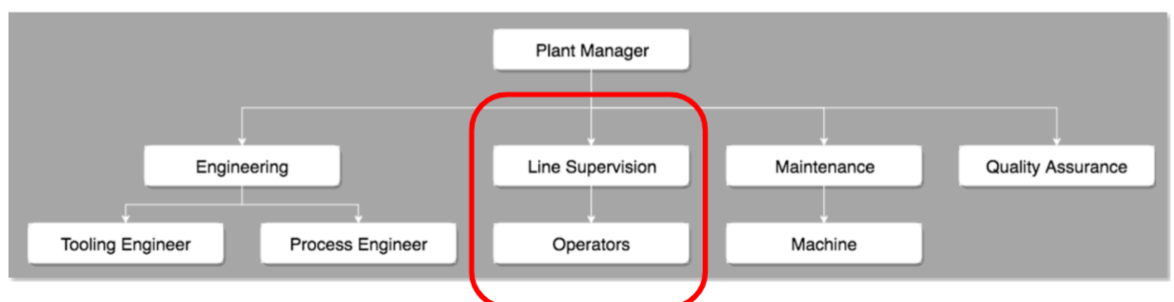
## Leverage Your Experts



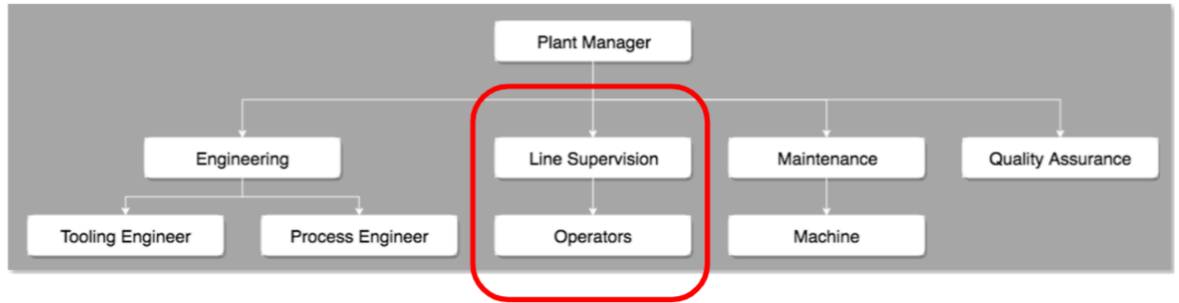
- **Leverage Your Experts**

- Processes efficiency
- Operations having trouble of it's bottlenecks
- Consider what the blind spots are. The don't know operational challenges. That's an opportunity

## Leverage Your Experts

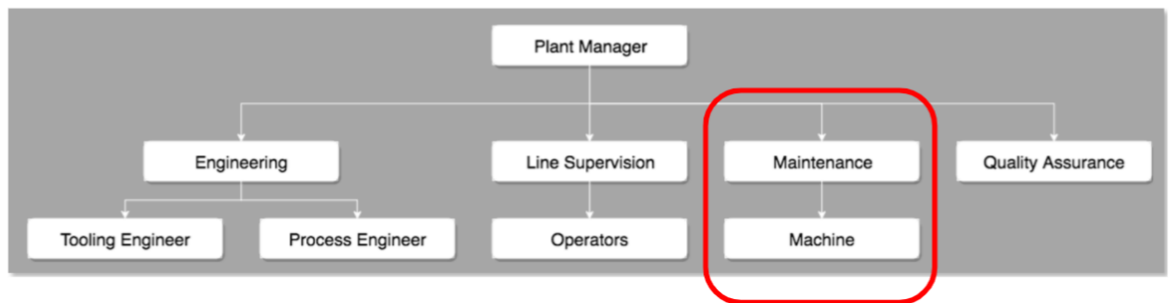


## Leverage Your Experts

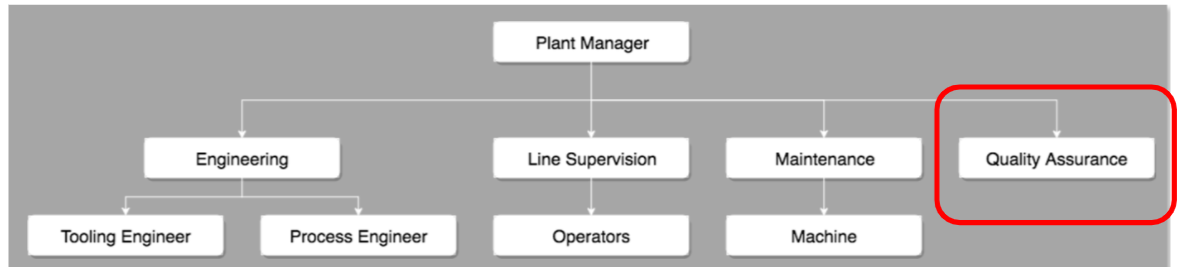


- Talk to the people who are closest to the manufacturing lines

## Leverage Your Experts



## Leverage Your Experts



## Three Search Strategies

Pain Points &  
Cost Drivers

Common Manufacturing  
Applications

Common Tooling  
& Fixtures Materials

- **Three Search Strategies**



## Pain Points & Cost Drivers

- **Pain Points & Cost Drivers**

## What Does It Cost?

Cost is highly **measured**

**Process** cost reduction opportunities → biggest ROI

Ask yourself what it costs!

- **What Does it Cost?**
  - ROI = Return Of Investment

## Cost Reduction Opportunities

Unplanned downtime mitigation

Line changeover calibration

Equipment upgrades and CapEx avoidance

'Cardboard engineering'



- **Cost Reduction Opportunities**
  - Mitigation = Verzachting. Effecten verminderen
  - Changeover = Omschakelen.

## Unplanned Downtime



Unexpected production stoppage

Equipment or manufacturing line failure

Downtime → **lost \$\$\$**



- **Unplanned Downtime**



## Unplanned Downtime Mitigation

High value/hour manufacturing  
Production stoppage → lost revenue  
Look for mission critical parts which  
block production



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- **Unplanned Downtime Mitigation**
  - Revenue = winst

## Line Changeover and Calibration

Product changeover → Re-calibrate line configuration  
Undocumented parameters cost days of labor, downtime  
3D printed changeover calibration jigs bring lines up faster and cheaper

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- **Line Changeover and Calibration**



- **Example: Adjustable Conveyor Guide**

## Equipment Upgrades and CapEx Avoidance



Aging equipment often upgraded with modern sensors and parts  
Improves productivity, efficiency, up-time  
Sensor brackets are slow to machine, low priority for in-house shop

- **Equipment Upgrades and CapEx Avoidance**



- **Example: Adjustable Sensor Mount**

## 'Cardboard Engineering'

Temporary calibration solutions that  
turn permanent

Not documented record of specific  
fix or positioning

High time and labor cost between  
manufacturing line changeovers



- **'Cardboard Engineering'**





- **Example: Cardboard Engineering**



## Questions to Ask Yourself

What area [of a specific process] is costing you the most?

What are your biggest causes of loss, waste, scrap or unnecessary manufacturing cost?

What breaks/is replaced often? How much does it cost when it does?

What are your sources of unplanned downtime?

What parts do you absolutely need to stay running?

Do you have any areas where things are fixed with [duct tape, cardboard, zip ties, etc]?

Do those cause issues when updating lines?



- **Questions to Ask Yourself**

## Your Experts

Plant Manager

Manufacturing Supervisor/Manager

Production Supervisor/Manager/Engineer

Maintenance Supervisor/Manager/Engineer

Machine Operators



- **Your Experts**



## Categorizing Common Manufacturing Applications

- **Common Manufacturing Applications**

## Typical Application Categories

Fixturing, Positioning &  
Tooling

Machine Setup

Line Optimization

- **Typical Application Categories**



## Typical Application Categories

### Fixturing, Positioning & Tooling

- Inspection and assembly fixtures
- Soft jaws
- Alignment features that are hard to machine

Machine Setup

Line Optimization

## Typical Application Categories

### Machine Setup

- Calibration jigs
- Machine repair and maintenance tools
- Improved startup efficiency

Fixturing, Positioning & Tooling

Line Optimization

## Typical Application Categories

Fixturing, Positioning &  
Tooling

Machine Setup

### Line Optimization

- Custom end effectors
- Line add-ons and upgrades
- Improve line efficiency and safety

## Typical Application Categories

### Fixturing, Positioning & Tooling

- Inspection and assembly fixtures
- Soft jaws
- Alignment features that are hard to machine

### Machine Setup

- Calibration jigs
- Machine repair and maintenance tools
- Improved startup efficiency

### Line Optimization

- Custom end effectors
- Line add-ons and upgrades
- Improve line efficiency and safety

- **Immediate vs ROI**

## Typical Application Categories

### Fixturing, Positioning & Tooling

- Inspection and assembly fixtures
- Soft jaws
- Alignment features that are hard to machine

### Machine Setup

- Calibration jigs
- Machine repair and maintenance tools
- Improved startup efficiency

### Line Optimization

- Custom end effectors
- Line add-ons and upgrades
- Improve line efficiency and safety

Existing Markforged ROI



- Immediate contribution to your operation and quickly ROI.

## Typical Application Categories

### Fixturing, Positioning & Tooling

- Inspection and assembly fixtures
- Soft jaws
- Alignment features that are hard to machine

### Machine Setup

- Calibration jigs
- Machine repair and maintenance tools
- Improved startup efficiency

### Line Optimization

- Custom end effectors
- Line add-ons and upgrades
- Improve line efficiency and safety

Future Markforged ROI



- Future

## Questions to Ask Yourself

Where do you use the most fixturing and workholding?

Do you have an inspection/QC/QA room? How do they fixture parts?

Do you do assembly in-house? Do you build your own fixtures?

How much does out-of-house fixturing cost?

What longer-term process/line improvement projects are you planning in the next 6-12 months?

- **Questions to Ask Yourself**

## Your Experts: Searching by Application

Production Engineer

Manufacturing Engineer

Maintenance Engineer

QA/QC Manager/Engineer/Technician

- **Your Experts: Searching by Application**

## Common Materials In Tooling & Fixtures

- **Common Materials**

## Potential Materials Replacement

### Plastics:

UHMW  
Delrin® (acetal)  
Nylon  
Teflon\*

### Metals:

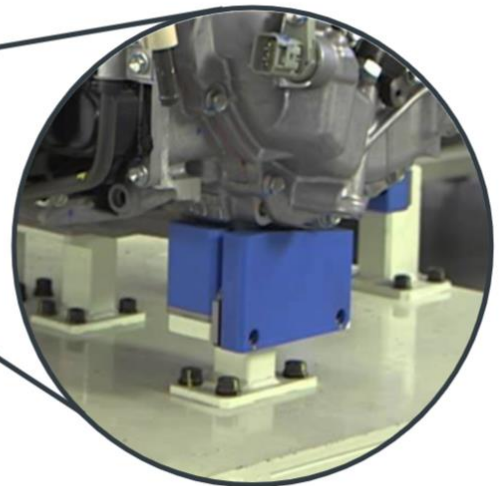
Aluminum  
Tool Steel\*  
Stainless Steel\*  
Carbide\*

\* Properties can be matched with inserts

- **Potential Materials Replacement**



- **Manufacturing Plant Example**



Engineering plastics often used for non-marring fixtures and cradles:

- Nylon
- UHMW
- Acetal Resin (Delrin®)

- **Fixtures and Engineering Plastics**

- Non-marring = not causing damage.
- Cradles = wieg



UHMW and Delrin used for impact-resistant cradles

Onyx + Kevlar is often much faster/cheaper for both simple and complex fixtures



- **Vehicle Carriage Fixture**

## Questions to Ask Yourself

Do you use Nylon, Delrin (acetal) or UHMW in manufacturing applications in your plant and where?

Are you using aluminum, tool steel, stainless steel anywhere? Do they need to be made from those materials or are they just readily available/on hand?

How long does it take to have parts manufactured in the above materials in- or out-of house? What effect would it have if you could have 1-2 day turn-around on similar parts?

- **Questions to Ask Yourself**

- Readily = Gemakkelijk

## Your Experts: Searching By Materials

Production Engineer

Manufacturing Engineer

Maintenance Engineer

Tooling Engineer

- **Your Experts: Searching By Materials**

DEBRIEF:

What potential opportunities are you thinking about?

- **Debrief: Your Opportunities**
  - Debrief = Nabespreking.

## Review: Key Takeaways

**Challenge** your assumptions about what problems 3DP can solve

**Discover** opportunities via search strategies

Identify new aspects of value to add to your **ROI**

- **Review: Key Takeaways**

## Module Review

- **Module Review**

Bringing a manufacturing line down for planned maintenance and re-configuration for making a different product type with it, is considered a form of:

- 3D printing
- Manufacturing line changeover
- Scrap rate
- Unplanned downtime

What type of pain point or cost driver does this image of a fixture most directly represent?

- Cardboard engineering
- Unplanned downtime
- Sensor mount hardware
- Line maintenance



True/False: It can be possible to replace a custom fixture made from a harder material like tool steel with a composite-reinforced 3D printed part.

- True
- False

### Results

Your Score: 100% (30 points)  
Passing Score: 80% (24 points)


### Result:

✓ Congratulations, you passed.

Finish Module

Review Quiz

## C2.6 – Selecting a Continuous Fiber for Your Application



Markforged University – Essential Composites  
**Selecting a Continuous Fiber  
For Your Application**

- **Selecting a Continuous Fiber for Your Application**

☰ C2.6 - Selecting a Fiber for Your Application

## Module Overview

Fiber Selection Strategy

Markforged CFF Portfolio Properties

Guess That Fiber!



- **Module Overview**

☰ C2.6 - Selecting a Fiber for Your Application

## Learning Objectives:

By the end of this module, you will be able to:

1. Identify the key properties of each type of CFF reinforcement fiber
2. Assess the environmental and loading conditions of a given part
3. Determine the material requirements of the part based on its environment and loading conditions
4. Select a best fit reinforcement fiber or fibers for the application



- **Learning Objectives:**

- Assess = Schatten



## What questions do we ask to evaluate a part?



- **What questions do we ask to evaluate a part?**
  - Which environment conditions?
  - Which loading conditions?
  - Onyx mold with high strength temperature HSHT (High Strength High Temperature) Fiberglass to meet the requirements.

## Types of Fiber



- **Types of Fiber**

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass

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- **Fiberglass in practice**

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass

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- Beams with several material loaded by a 3kg weight.
- The Fiberglass beam returns to its' original shape.
- Onyx does not completely returns to its' position.

- ABS and PLA are completely overloaded.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

	Properties	Failure Behavior	Ideal Loading
Fiberglass	<ul style="list-style-type: none"> <li>• Robust and sturdy</li> <li>• Cost-effective</li> </ul>	<ul style="list-style-type: none"> <li>• Bends until fracture</li> </ul>	<ul style="list-style-type: none"> <li>• General-purpose loading</li> </ul>
Carbon Fiber	<ul style="list-style-type: none"> <li>• High stiffness</li> <li>• High strength-to-weight</li> </ul>	<ul style="list-style-type: none"> <li>• Stiff until fracture</li> </ul>	<ul style="list-style-type: none"> <li>• Constant loading</li> </ul>
Kevlar	<ul style="list-style-type: none"> <li>• Impact resistant</li> <li>• Tough</li> <li>• Abrasion resistant</li> </ul>	<ul style="list-style-type: none"> <li>• Bends until deformation</li> </ul>	<ul style="list-style-type: none"> <li>• Impact loading</li> </ul>
HSHT Fiberglass	<ul style="list-style-type: none"> <li>• High heat deflection temp</li> <li>• High energy absorption</li> </ul>	<ul style="list-style-type: none"> <li>• Bends until fracture</li> </ul>	<ul style="list-style-type: none"> <li>• Constant loading at high temperatures</li> </ul>

- **Fiberglass Properties**

- In mass critical application is Carbon a better choice.
- But it is a great default material.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

Fiberglass	
Carbon Fiber	
Kevlar	
HSHT Fiberglass	

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- **Carbon Fiber in Practice**

- Strongest and stiffest material.

- Comparison: Left Onyx Carbon reinforced and right aluminum (with exact the same geometry).

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES


## Types of Fiber

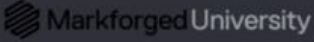
Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass



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- Aluminum beam deforms.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

	Properties	Failure Behavior	Ideal Loading
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- **Carbon Fiber Properties**

- Applications: Drone arms, automation tooling, etc.
- High stiffness is not at good absorb impact loading.
  - Needs more testing in high frequently loading conditions.

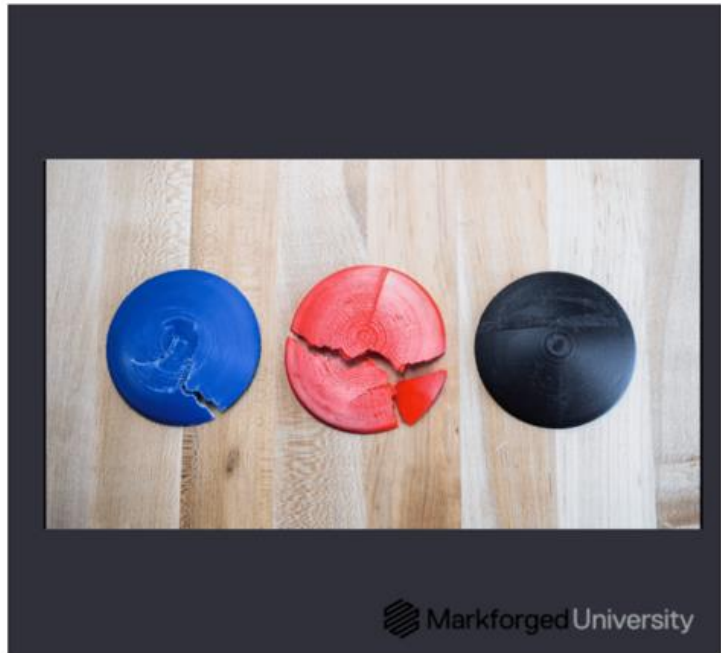
## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass



- **Kevlar in Practice**
  - Extremely impact resistant.
    - Comparison: ABS, PLA and Kevlar.

## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass

	Properties	Failure Behavior	Ideal Loading
Fiberglass	<ul style="list-style-type: none"> <li>• Robust and sturdy</li> <li>• Cost-effective</li> </ul>	<ul style="list-style-type: none"> <li>• Bends until fracture</li> </ul>	<ul style="list-style-type: none"> <li>• General-purpose loading</li> </ul>
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- **Kevlar Properties**
  - Abrasion = Slijtage.

- Stress strain curves shows failing in 3 point bending for a half of load of carbon, for instance.
- Applications: Reinforcing clamps rotating axis, soft jaws for CNC-lathes.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass

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- **HSTS Fiberglass in Practice**

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

Fiberglass

Carbon Fiber

Kevlar

HSHT Fiberglass

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- Heated in an environmental chamber to 140 °C, for an hour, before applying load.



- Fiberglass beam just slightly bends and returns immediately to its' original shape.
- PLA and ABS lost their stiffnesses.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

	Properties	Failure Behavior	Ideal Loading
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- **HSTS Fiberglass Properties**
  - Deflection = doorbuiging.
  - Print a little bit slower.

☰ C2.6 - Selecting a Fiber for Your Application RESOURCES

## Types of Fiber

	Properties	Failure Behavior	Ideal Loading
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- **Recap: Continuous Fiber Properties**



- **Guess That Fiber**

Tooling & Fixtures: 100

### Fischer Connectors: Mold Insert

- Overmolding application
- 30 tons clamp force
- 6.9 MPa of stress
- Low volume

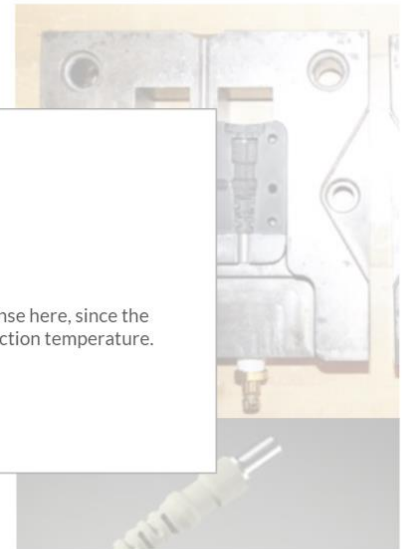
Pick 1

Carbon

Fiberglass

Kevlar

HSHT Fiberglass



Correct

That's right! HSHT Fiberglass is the only fiber that makes sense here, since the elevated temperatures require a material with a higher deflection temperature.

Continue

End Use: 200

### Humanetics: Crash Test Dummy Ribs

- The ribs see some of the highest stresses during a crash
- Somewhat unknown loading directions
- Impact resistant
- Previous plastic iterations failed after 20 impacts



Pick 1

- Carbon Fiber
- Fiberglass
- Kevlar**
- HSHT Fiberglass



Correct



Prototyping: 200

### BattleBots Team Valkyrie: Skid Pad

- Attaches to the bottom of the blade
- Spins against the ground at 2000 RPM
- Support the weight of a 250 lb robot as one of three points of contact



Pick 1

- Carbon Fiber
- Fiberglass
- Kevlar**
- HSHT Fiberglass



Correct



Prototyping: 300

### Moterum Technologies: Stroke Mobility Device

- Support the weight of a person from multiple contact points
- Capable of handling gait-related loading conditions and impacts
- Light enough to not further impair gait



Pick 1

- Carbon Fiber
- Fiberglass
- Kevlar**
- HSHT Fiberglass

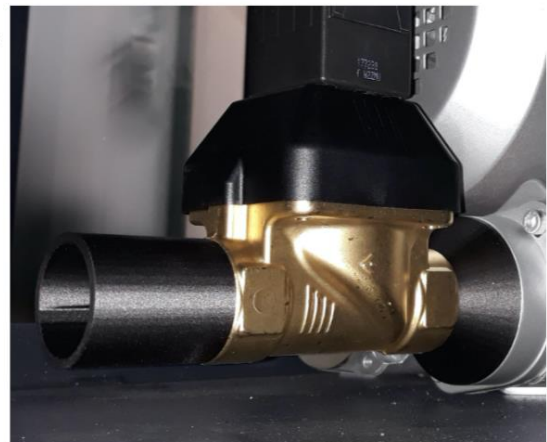


Correct ✕

End Use: 100

### BMF GmbH: Tube Extension

- Tube extension for sand blasting machine
- Needs to be wear resistant
- Low pressure
- Minimal loading



Pick 1

- Carbon Fiber**
- Fiberglass
- Kevlar
- HSHT Fiberglass**

End Use: 300

### Haddington Dynamics: Dexter Arm

- 7-axis robotic arm
- 50 micron joint precision
- 3kg payload
- 70 printed parts, focusing on arm segments

Pick 1

Carbon Fiber

Fiberglass

Kevlar

HSHT Fiberglass



Correct



Tooling & Fixtures: 200

### Primetall: Welding Fixture

- Zero-point clamping system for spot welding
- Durable, dimensionally stable
- Holding heavy steel while rotating at high speed
- Not a high load application

Pick 1

Carbon Fiber

Fiberglass

Kevlar

HSHT Fiberglass



Incorrect





Prototyping: 100

### Surf Flex Lab: Surfboard Fin

- Attaches to the bottom of the board
- Complex loading condition when in testing
- Marine application
- Needs to be strong and stiff



Pick 1

Carbon Fiber

Fiberglass

Kevlar

HSHT Fiberglass

Incorrect



Results

Your Score: **57.14% (40 points)**

Finish Module

Review Quiz



## C2.7 – Business Impacts of AM Adoption

☰ C2.7 - Business Impacts of AM Adoption RESOURCES



Markforged University – Essential Composites

# Business Impacts of AM Adoption

Markforged University

- **Business Impacts of AM Adoption**


-



GOAL:  
Understand the total business value realized by adopting 3D printing




- **Its's All About the Total Value**
  - Comprehensive = samenhangend



Design for AM (DfAM)  
means designing to solve a problem with 3D printing...

...and choosing the right problem to solve



- **Choosing the Right Problem**

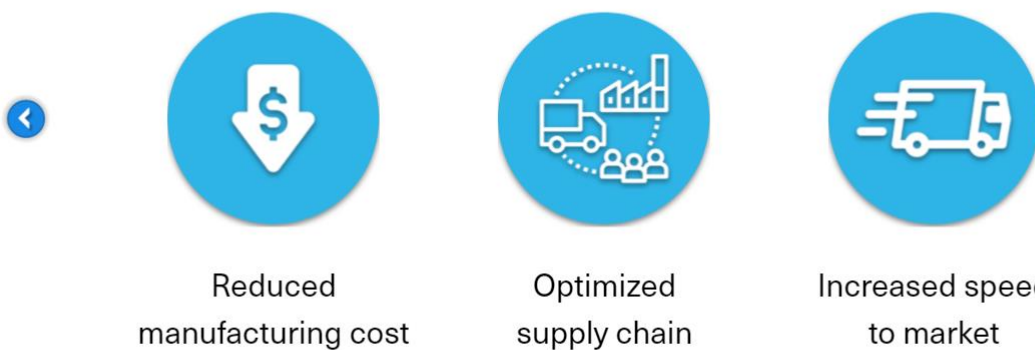
There are many different challenges that manufacturers face

3D printing tends to make an impact for them in **three** broad areas



- **Business Impacts In Manufacturing**

### Three Main Value Drivers



Reduced manufacturing cost

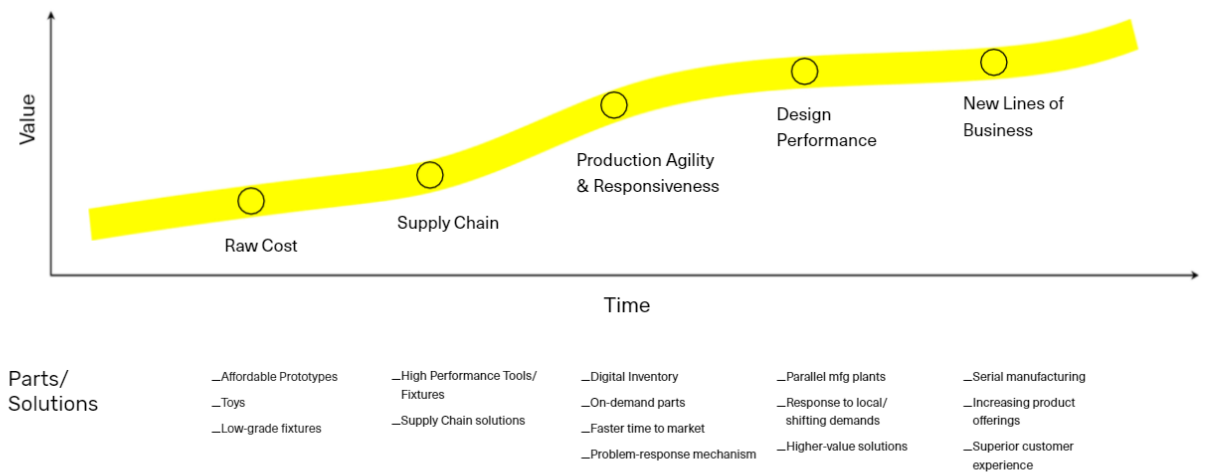
Optimized supply chain

Increased speed to market



- **Two Types of Impact**

## Additive Maturity Model



- **AM Maturity Trajectory**

- Maturity = Volwassenheid
- Agility = Behendigheid
- Responsiveness = Ontvankelijkheid
- Increasing product offerings = Toename in offertes.

- Superior = betere

☰ C2.7 - Business Impacts of AM Adoption

## Immediate Impacts Revisited



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- **Immediate Impacts Revisited**
  - Revisited = Opnieuw bekeken

## Immediate Impacts Revisited

**Immediate Business Outcomes (per 3 jaw set):**

	Traditional	Markforged	Change
Cost	\$1000	\$81	-92%
Lead Time	2 weeks	30 hours	-91%



- Lead Time = Doorlooptijd



THEME:

Process improvements drive Organizational Impacts and result in larger, recurring benefits





- **Organizational Benefits Are Greater**

- Recurring = Terugkerend
- Benefit = Voordeel

☰ C2.7 - Business Impacts of AM Adoption

## Organizational Benefits: Much, Much More

Resource Utilization

Cycle Time & Throughput

Line Change Over Efficiency

Supply Chain Logistics

EH&S

Inventory Holding Costs

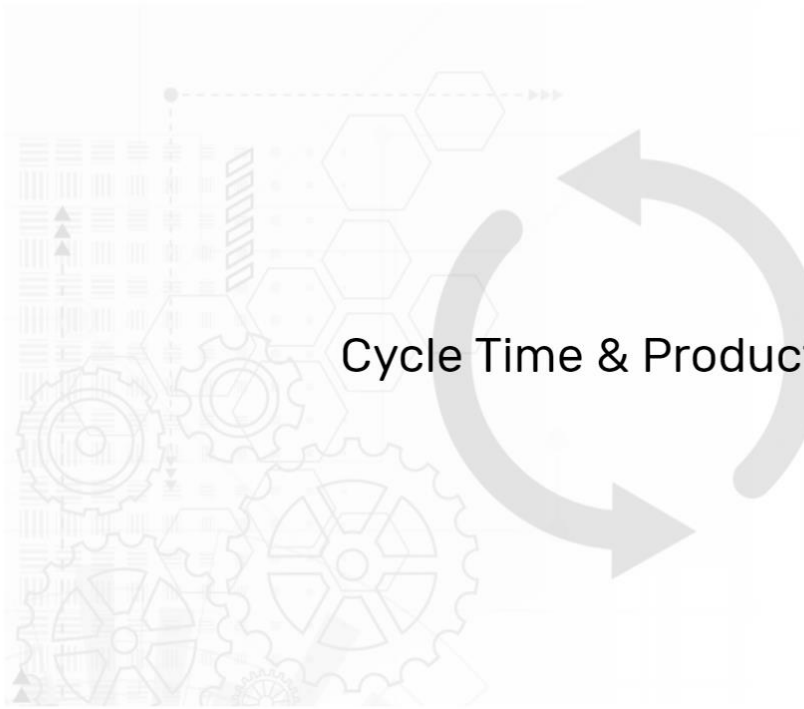
Innovative Culture Shift

Engineering Efficiency



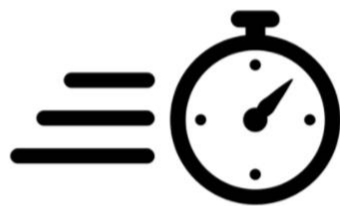
- **Organizational Benefits: Much, Much More**

- Resource Utilization = Gebruik van hulpbronnen
- EH&S = Environment, Health and Safety



- **Cycle Time & Productivity**

## Two Effects on Throughput



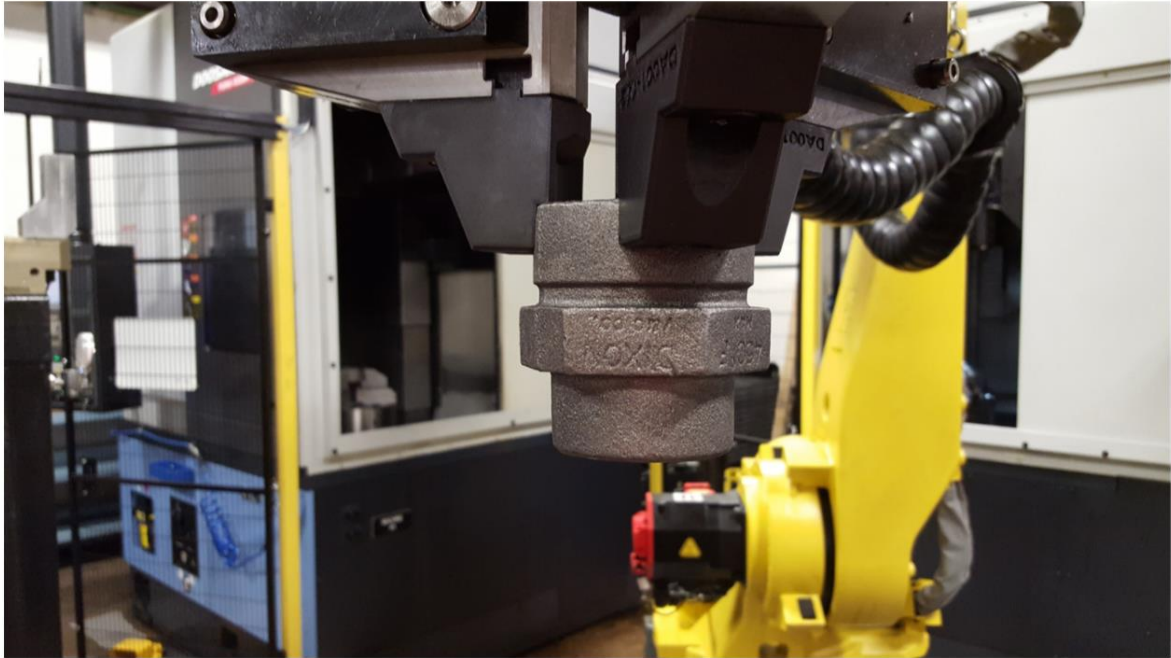
Increase production speed



Reduce scrap/increase yield

- **Two Effects on Throughput**
  - Throughput = Doorvoer

- **Poka yoke** is een Japanse term gebruikt in lean manufacturing en betekent zoveel als foutpreventie. Het is een methode om een productieproces zodanig te vormen dat het bijna onmogelijk wordt om fouten te maken. Een operatie wordt uitgevoerd op een manier dat de correcte handeling geforceerd wordt.



- **Reducing Cycle Time...and More!**

- By using metal EOAT decreases the acceleration deceleration. By using lower weight plastics increases speed of movement.



- Smaller and less expensive robots are required.

☰ C2.7 - Business Impacts of AM Adoption

## Other Cycle Time Reductions

- Heating/cooling cycles
- Lightweight hand tools
- Lower impact from tooling on process speed



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- **Other Cycle Time Reductions**

☰ C2.7 - Business Impacts of AM Adoption

## Supply Chain & Logistics Costs

- **Supply Chain & Logistics Costs**

- Bevoorradingsketen
- Disruption = verstoring

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## Reduced Supply Chain Friction

Facility-level 3D printing can reduce costs and risk due to:

Supplier issues

Import and export delays

Customs

Tariffs



- **Reduced Supply Chain Friction**

## Digital Distribution, Local Production

Online software enables global collaboration + 3D model distribution

Localized printing simplifies and reduces cost of production logistics



- **Digital Distribution, Local Production**



- **Inventory Holding Costs**
  - Voorraadkosten.

## Recurring Costs of Holding Inventory



Inventory taxation



Facility overhead



Labor

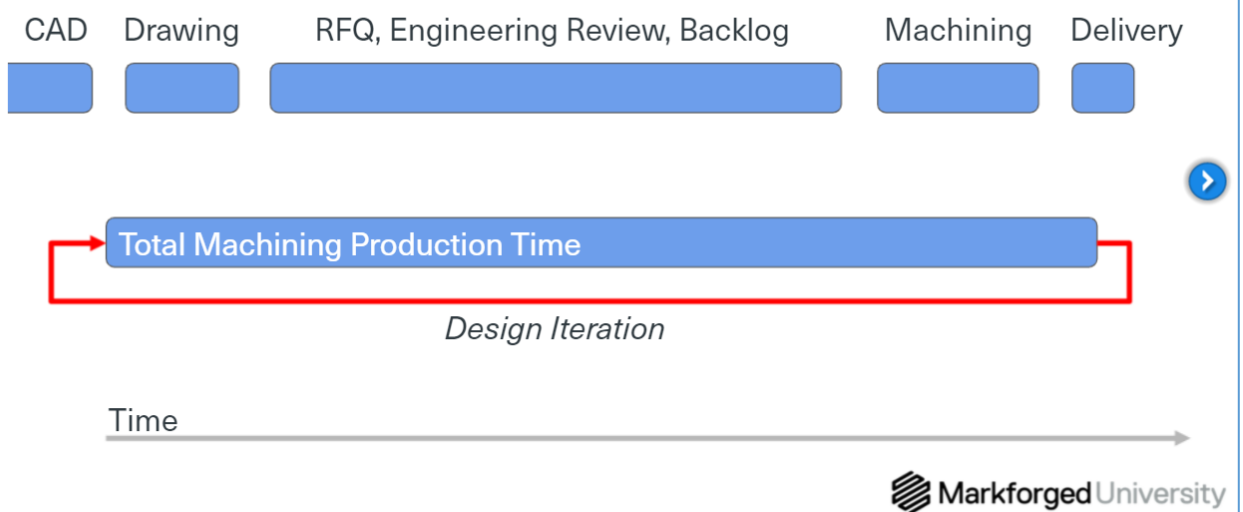
- **Recurring Costs of Holding Inventory**





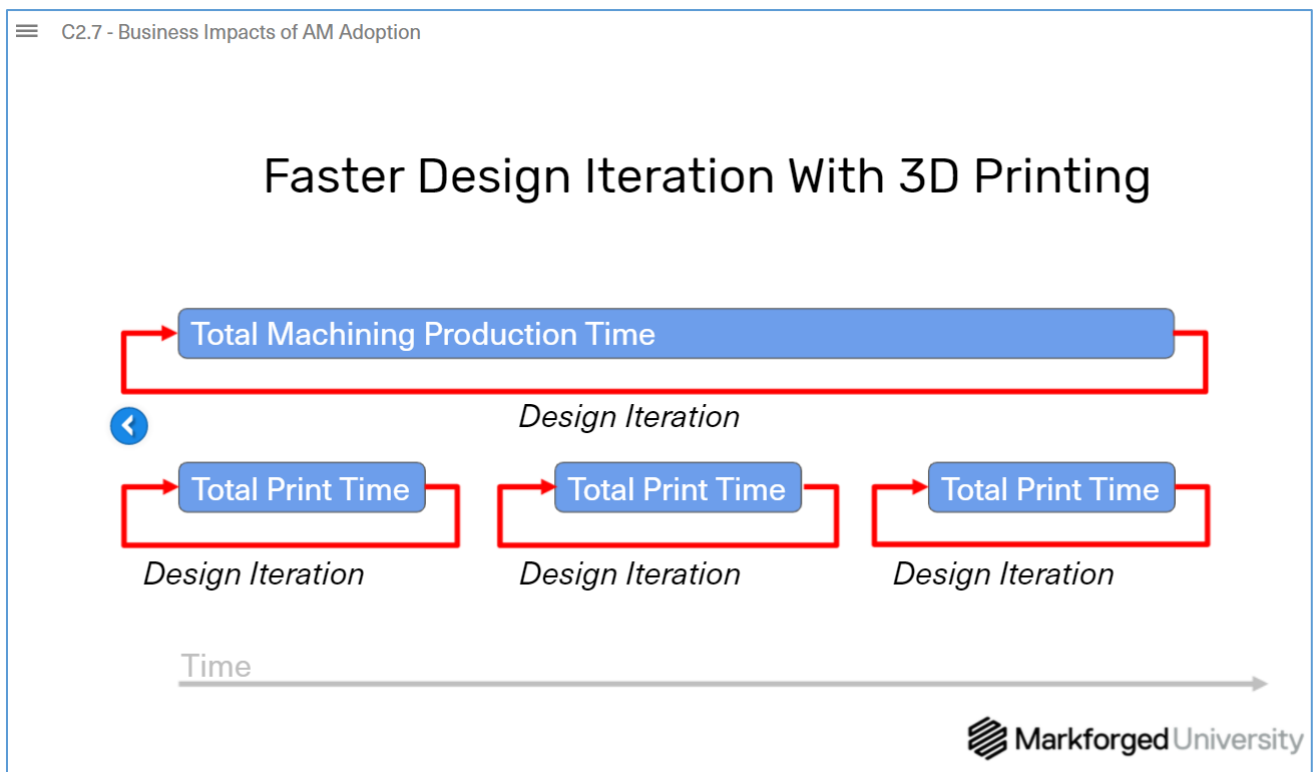
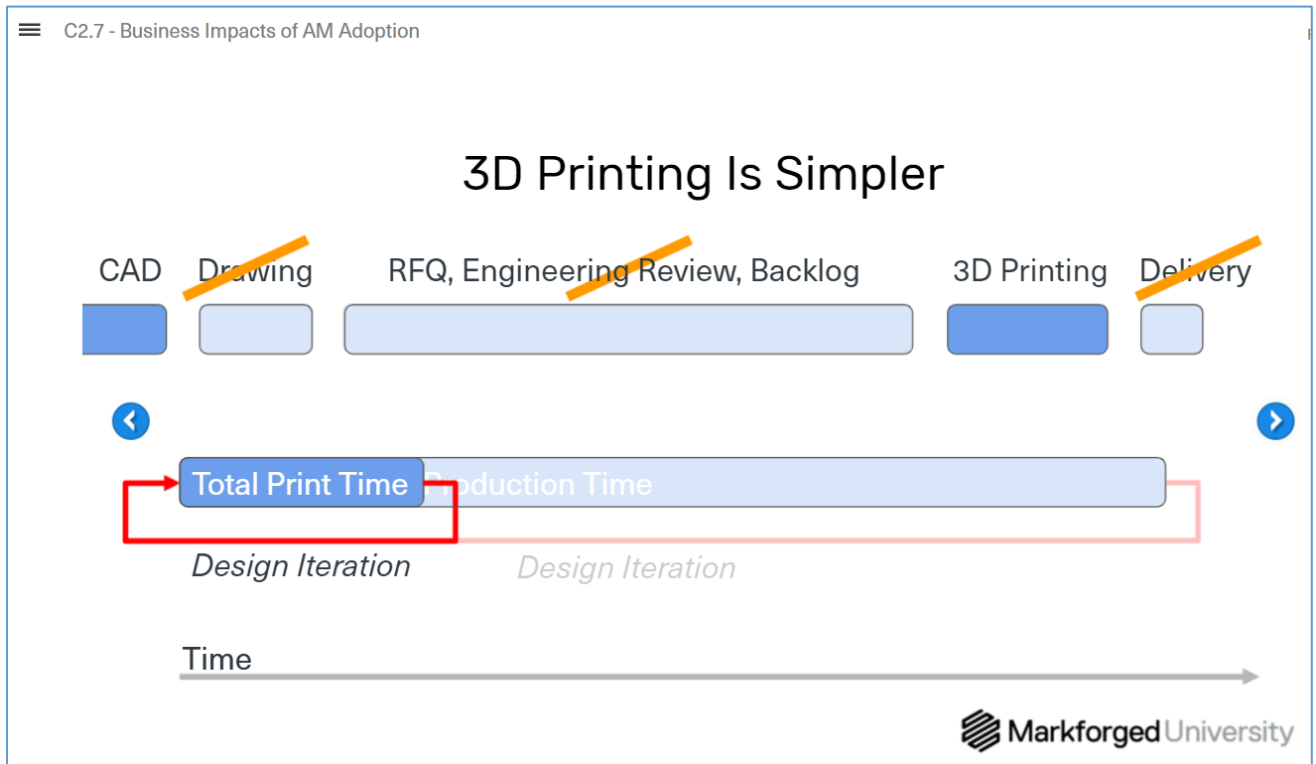
- **Engineering Efficiency**
  - Maturing tools faster with less effort
  - Maturing = Rijping (in deze context: op elkaar volgende verbeteringen).

## Time Costs of Outsourced Tooling



- **Time Costs of Outsourced Tooling**

- RFQ = Request for Quote = Offerte aanvragen
- Backlog = Achterstand



- More maturing of end product due to more iteration moments.



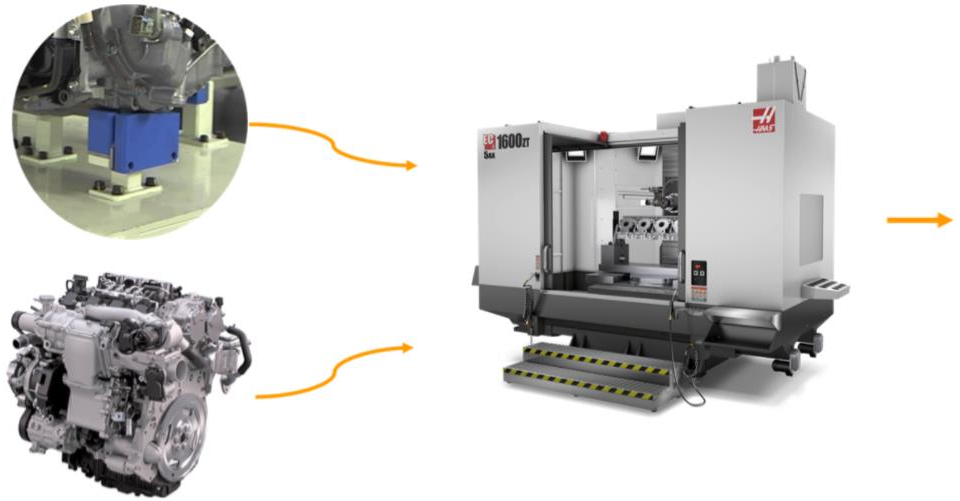
## Resource Utilization Efficiency

- **Resource Utilization Efficiency**
  - Efficiënt gebruik maken van hulpbronnen



- **Tools and Products**

## Before



- **Before and After**

- You can't buy a CNC-machine to solve the problem

## After



- Production has the higher priority.
- To add more CNC-machines is not an option (not only investment cost, also floorcapacity and laborcapacity).

- 3D printing of tooling creates more band width on CNC (by reducing demand on tooling needs). At the same time you have add significant production capacity.
  - 3D-printings works without supervision (produces through the night, without labor).
  - Achievement of highest value were each machine suited for.



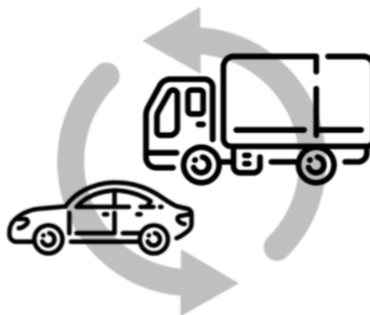
## Line Tool-Up and Changeover Efficiency

- **Line Tool-Up and Changeover Efficiency**

## Line Tool-Up and Changeover Efficiency



Faster initial tool-up



Faster changeover



Faster time-to-market

- **Line Tool-Up and Changeover Efficiency**



- **EHS Benefits**

- Environment, Health & Safety

## EHS Benefits



Ergonomics



Reduced injury rate



Consistent cycle time

- **Better for Operators, Better for Business**

- Example: Due to getting tired of the operator the cycle time will increase.



- Benefit for all!



- **Innovative Culture Shift**

## 3D Printing Enables Continuous Improvement

Empower teams to propose and test  
plant improvements

Faster results → More innovation

Greater mindshare → Greater ideas



- **3D Printing Enables Continuous Improvement**



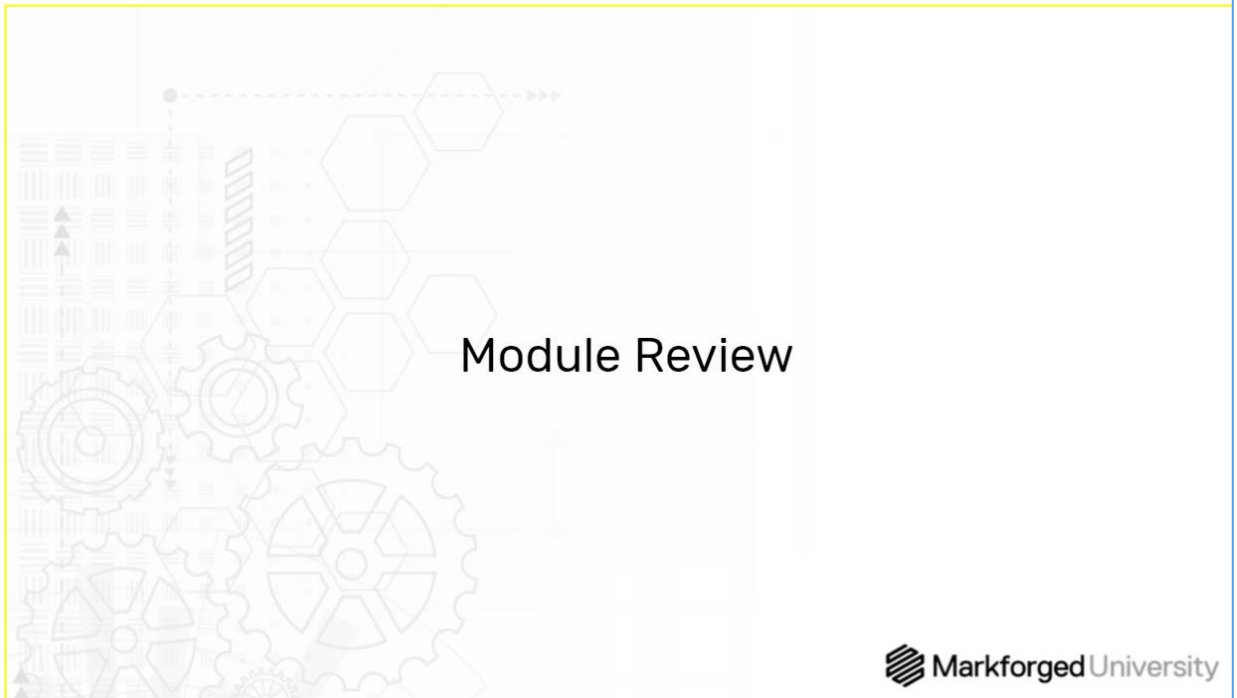
RECAP:  
**Organizational Impacts Dominate**

- **Recap: Organizational Impacts Dominate**



CONSIDER:  
**What are some key focus areas for impacting your operations with 3D printing?**

- **What Are Your Focus Areas?**
  - Wat zijn uw aandachtsgebieden?



- **Module Review**

Mark all the following which are examples of Organizational Impacts of AM adoption on a business.

- Reducing the scrap rate in a process by 3% with a 3D printed alignment guide
- Eliminating a recurring jam in a manufacturing line that caused downtime with a 3D printed guide rail
- Cutting the lead time of a machined part by 3 weeks by 3D printing it instead
- Saving \$500 on every CMM fixture by 3D printing them instead of sending to a vendor

A 3D printed tool which presents an operator with a set of the bolts they need in an assembly process, rather than requiring them to manually dig through a bin for them every time, is primarily an example of what kind of Organizational Impact?

- Vendor supply chain optimization
- Inventory holding cost reduction
- EHS improvements
- Reduced scrap rate

A fixture for holding a part in a gluing operation, that is performed at elevated temperature, was re-designed for 3D printing and with channels to allow conditioned airflow through to heat the part up faster beforehand and cool it down more quickly after adhesive application. What kind of organizational or operational impact describes the effect of these channels on the overall process.

- Reduced import duties
- Decreased cycle time
- Improved operator safety
- Inventory reduction via digital warehousing

## Results

Your Score: 100% (30 points)  
Passing Score: 80% (24 points)

---

### Result:



Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

Markforged University Advanced Composites



- **Welcome to Advanced Composites**

## Crawl, Walk, Run



- **Welcome to Advanced C**



## Where are we going?

A replicable, robust **framework** for **identifying, justifying** and **executing** on AM opportunities in your work

**Best practices** for designing parts that reflect AM's unique **capabilities** and **limitations**

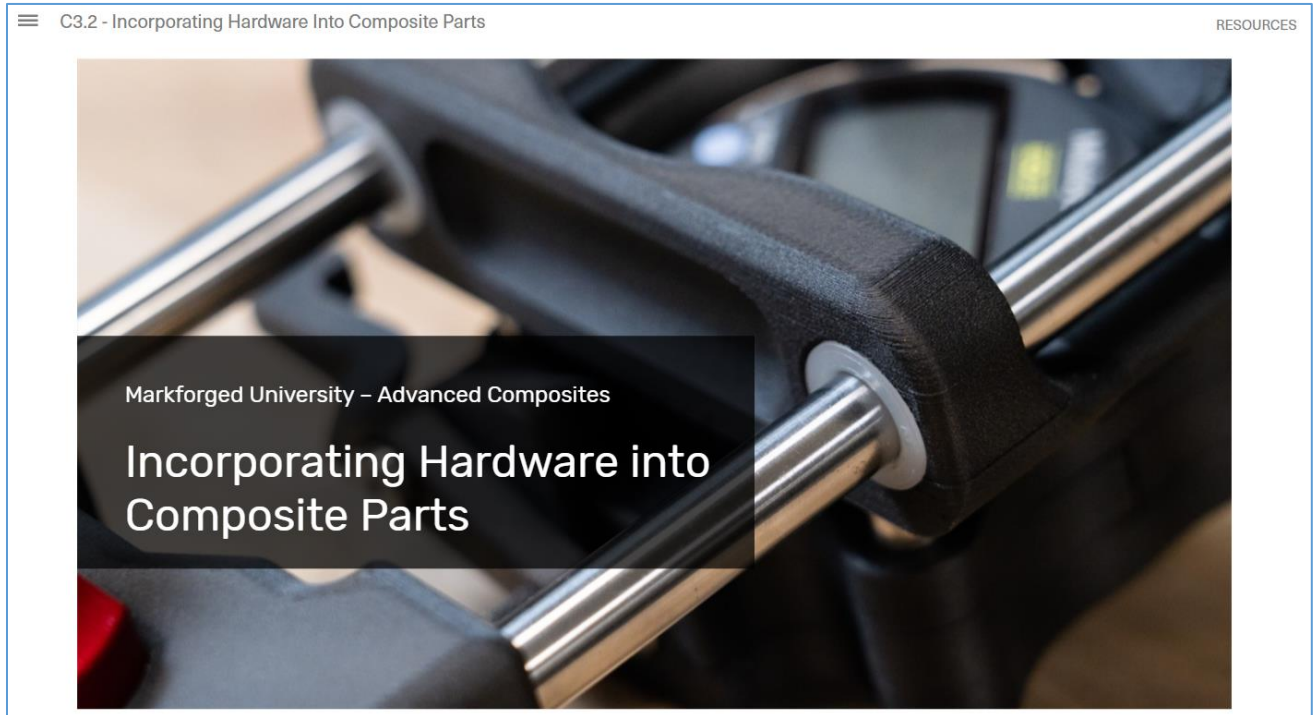
**Hands-on practice** working through example case studies on **AM adoption**

Finish Module



- **Where are we going?**
  - **Replicable = repliceerbaar:** de mate waarin een andere onderzoeker dezelfde proefneming kan uitvoeren en dezelfde resultaten krijgt.
  - Best practice = Beste werkwijzen / optimale werkmethoden.

## C3.2 – Incorporating Hardware Into Composite Parts



- **Incorporating Hardware into Composite Parts**
  - 
  - Incorporating = opnemen
  - Off the shelf components = boutjes, moeren, kortom DIN-materiaal wat je op voorraad hebt liggen.

## Module Overview

Identification via Functional Requirements

Bushings

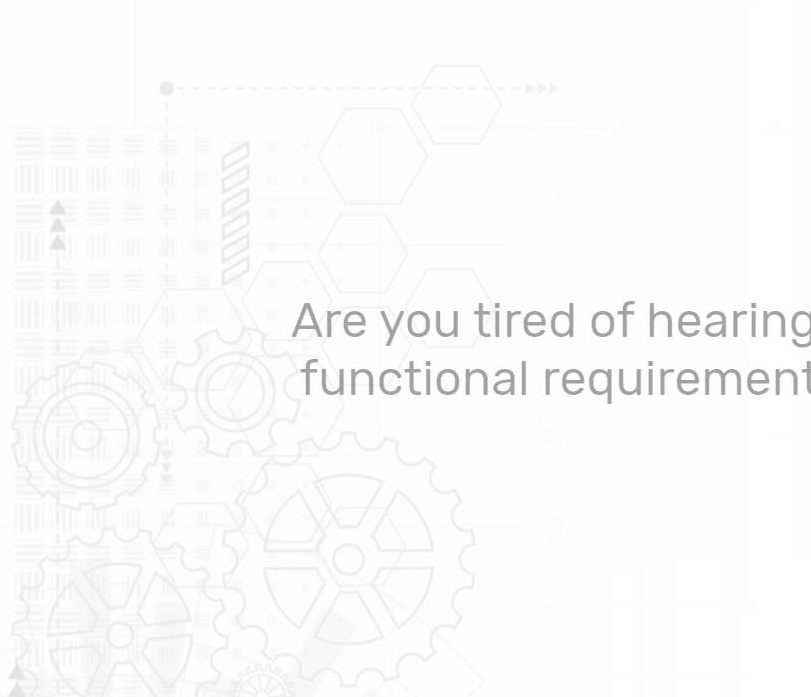
Abrasion-resistant Surfaces

Reinforcing Thin Pillars

Workholding with Grippers

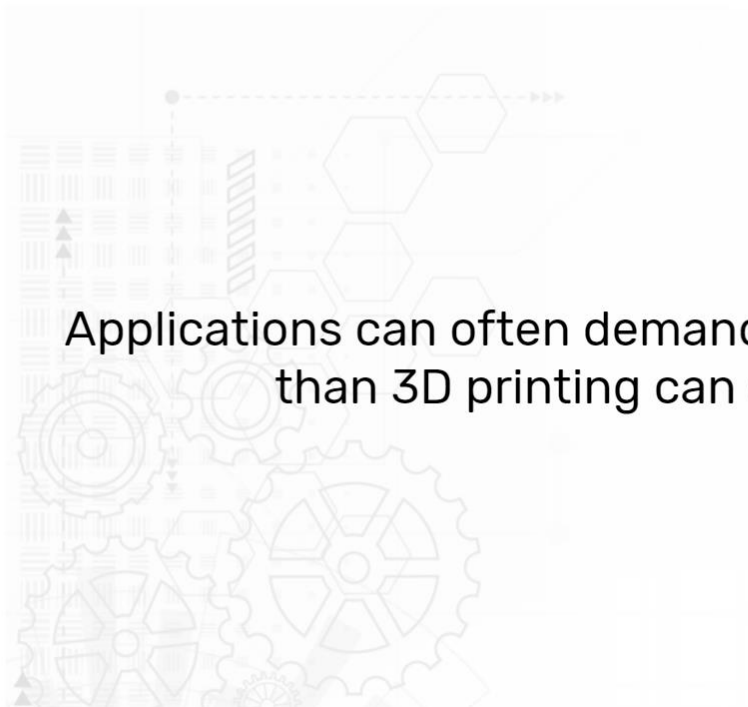
Adding Threaded Features

- **Module Overview**

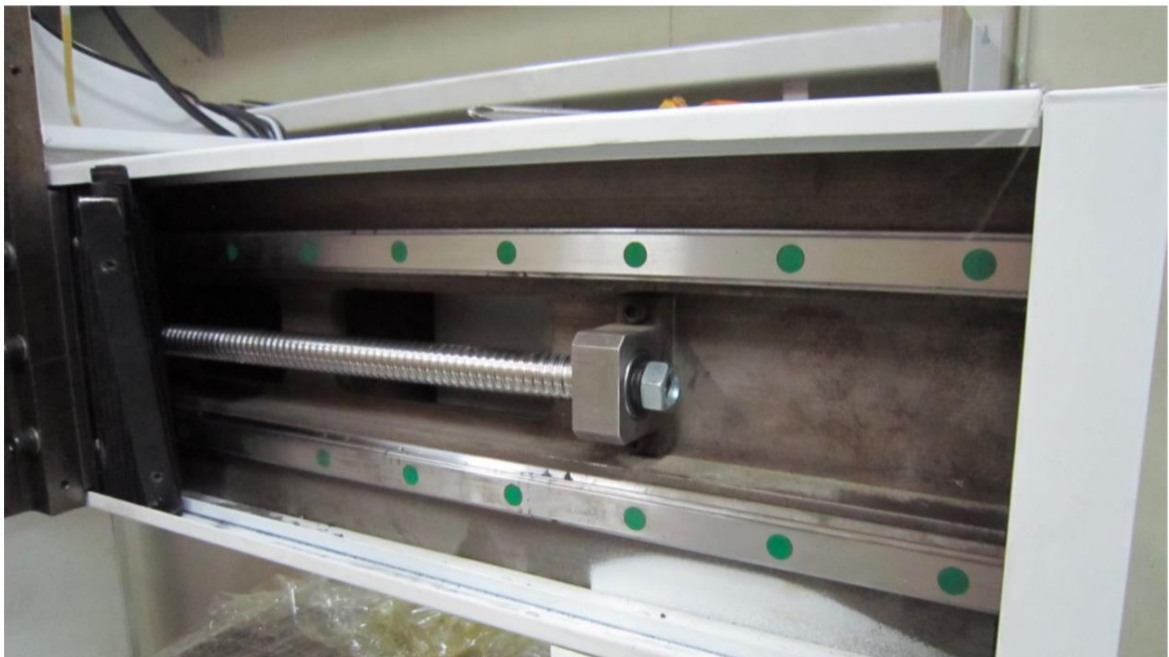


Are you tired of hearing about functional requirements yet?

- **Functional Requirements...Again!?!**



Applications can often demand more performance than 3D printing can offer alone

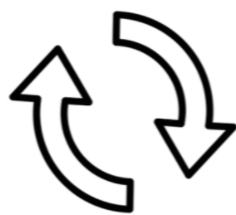


- **What are the functional requirements?**
  - Linear axis of a CNC-machine



- Bearing block of the ball screw.
- What kind of forces will take place?
- High level of replacing accuracy is needed.

### The bearing block may experience...



Cyclic, reciprocating loading



Axial tension



Abrasive particulate wear

- **The bearing block may experience...**
  - Reciprocating = over en weer.
  - Abrasive = schurend.

A plastic 3D printed part probably can't handle those conditions by itself...

- **A plastic 3D printed part probably can't handle those conditions by itself...**

The solution is to integrate off-the-shelf hardware that adds extra capabilities



## Reinforce Holes with Bushings

- **Reinforce Holes with Bushings**

## Sleeve Bearings/Bushings



- **Sleeve Bearings/Bushings**

- Wear resistant.
- Low friction.
- Self lubricating pressed in flanged fluid (oil) bearings

## When to Use a Bushing?

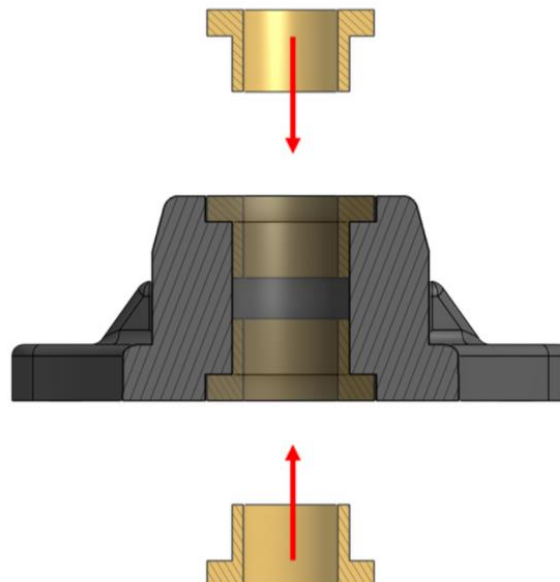
- Low-speed rotary/linear motion
- Rotation in an abrasive environment
- Reinforce holes
- Improved horizontal bore circularity
- Distribute compressive loading



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- **When to Use a Bushing?**

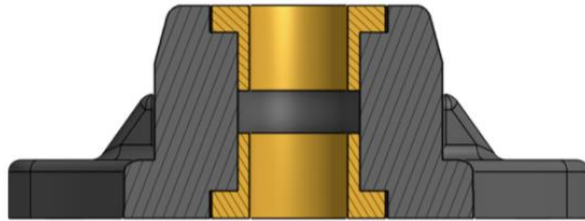
- Distribute compressive loading = verdelen van de last.



- **A Bushing, Assembled**

- Undersized press fit.

☰ C3.2 - Incorporating Hardware Into Composite Parts



☰ C3.2 - Incorporating Hardware Into Composite Parts

RESOURCES



- Example: Siemens Innovation Center



- Press fit and low friction bushings.
- Take notice of the print orientation: Don't have to worry about the circularity



## Abrasion Resistant Surfaces with Inserts

- **Abrasion Resistant Surfaces with Inserts**



## Dowel Pins Follow Curves

Press-fit dowel pins can create  
reinforce curved surfaces

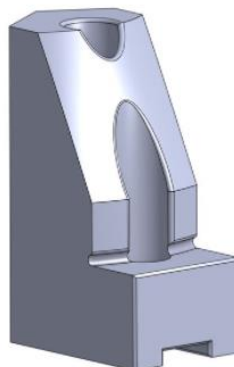
Choose a dowel pin diameter smaller  
than curve radius



- **Dowel Pins Follow Curves**

- Dowel Pins < 10mm = Undersized hole sizes -0.1mm, or so.
- Dowel Pins > 10mm = Undersized hole size by -1%.

## How to Design Dowel Pins In



- **How to Design Dowel Pins In**

- Gripper jaws as an example

☰ C3.2 - Incorporating Hardware Into Composite Parts RESOURCES

## How to Design Dowel Pins In

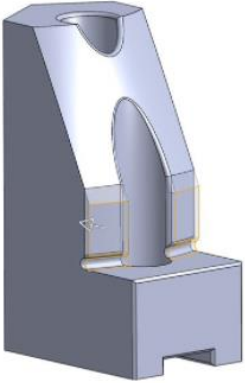



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- Region to reinforce

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## How to Design Dowel Pins In

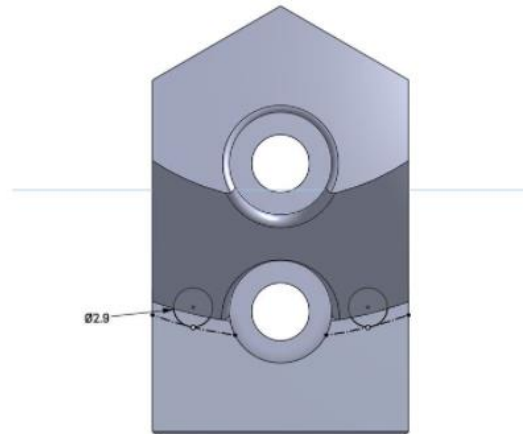


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- Cut the geometry

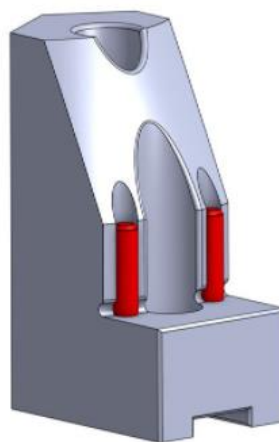


## How to Design Dowel Pins In



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## How to Design Dowel Pins In



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## Machine Keys Create Flat Wear Pads

Flat surfaces are easier to reinforce –  
don't have to match radii

Machine keys can be bought pre-cut  
to length and simply pressed into a  
part



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- **Machine Keys Create Flat Wear Pads**

## Easy Flat Contact Surfaces



Jaw needed wear resistance against  
a cast stainless steel part

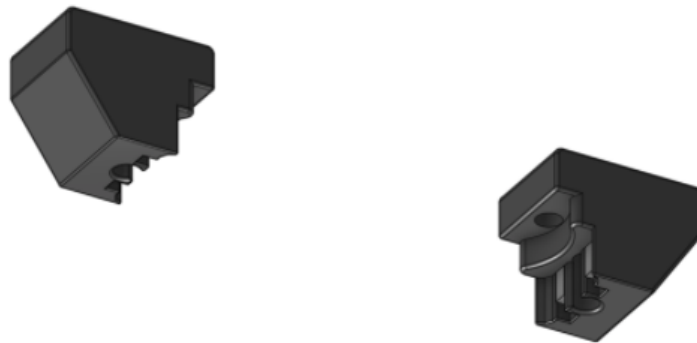
The gripped part had a flat contact  
surface

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- **Easy Flat Contact Surfaces**

☰ C3.2 - Incorporating Hardware Into Composite Parts

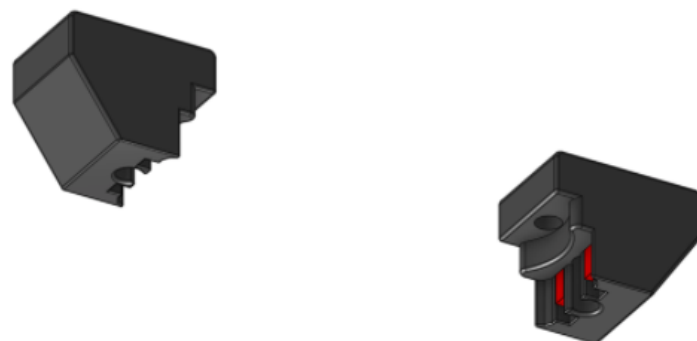
RESOURCES

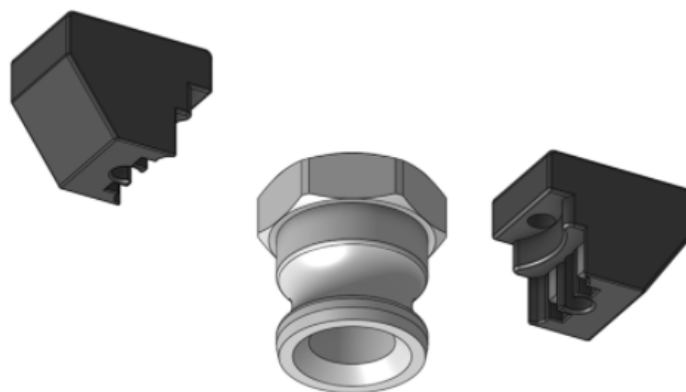
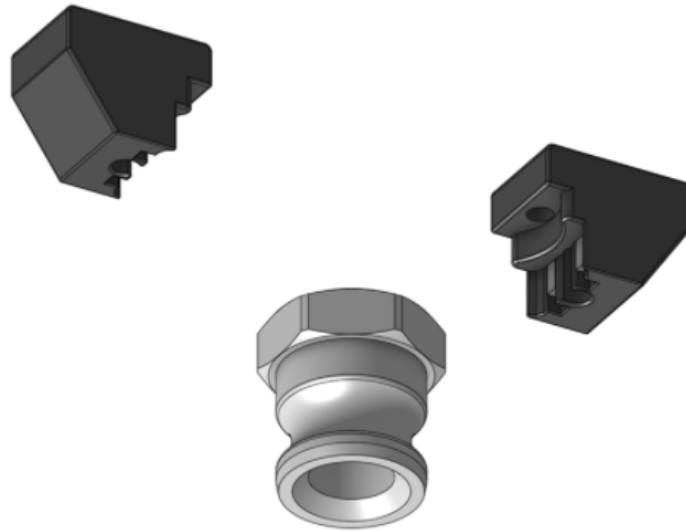


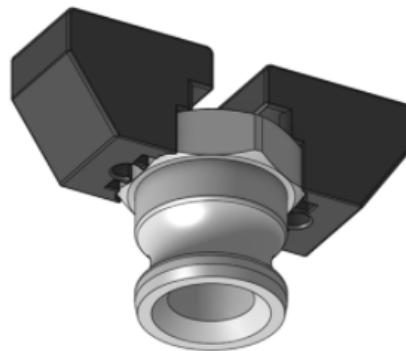
- **Reinforced Jaw in Action**

☰ C3.2 - Incorporating Hardware Into Composite Parts

RESOURCES



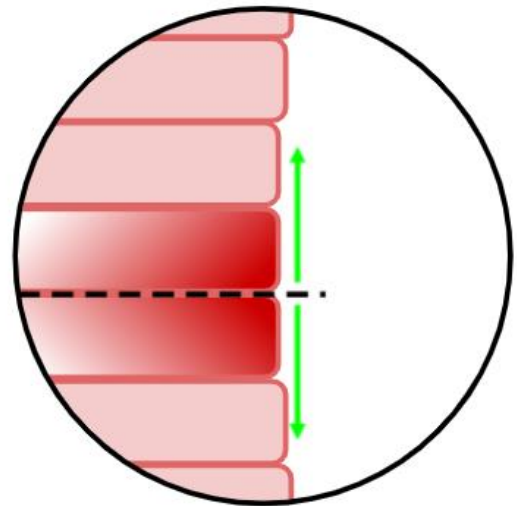
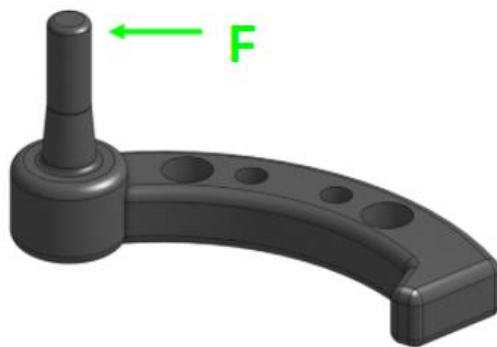




## Reinforcing Z-axis Pillars

- Reinforcing Z-axis Pillars

## High Aspect Ratio Features in Z-axis are Weak



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- High Aspect Ratio Features in Z-axis are Weak



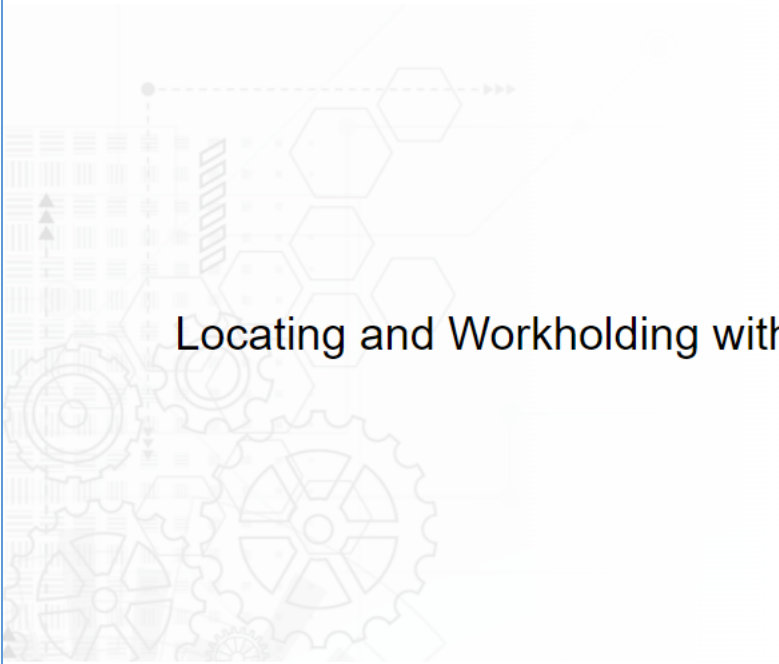


- **Example: Z-axis Reinforcement**

- With a dowel pin.



- Cross section.
- Resisting bending and shear load (afschuifbelasting).



## Locating and Workholding with Grippers

- **Locating and Workholding with Grippers**

## Fixture Grippers Bite Into A Workpiece

Pre-formed carbide or steel inserts that bolt, thread or press into a part

Isolate high hardness/grip strength properties to specific regions



- **Fixture Grippers Bite Into A Workpiece**

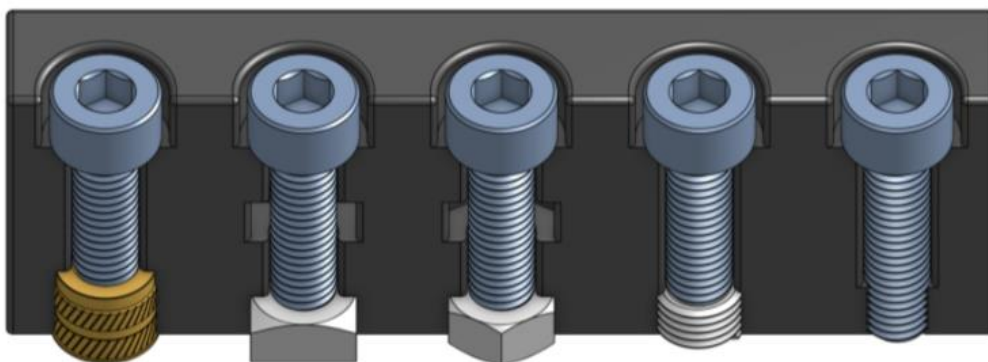


## Adding Threaded Features



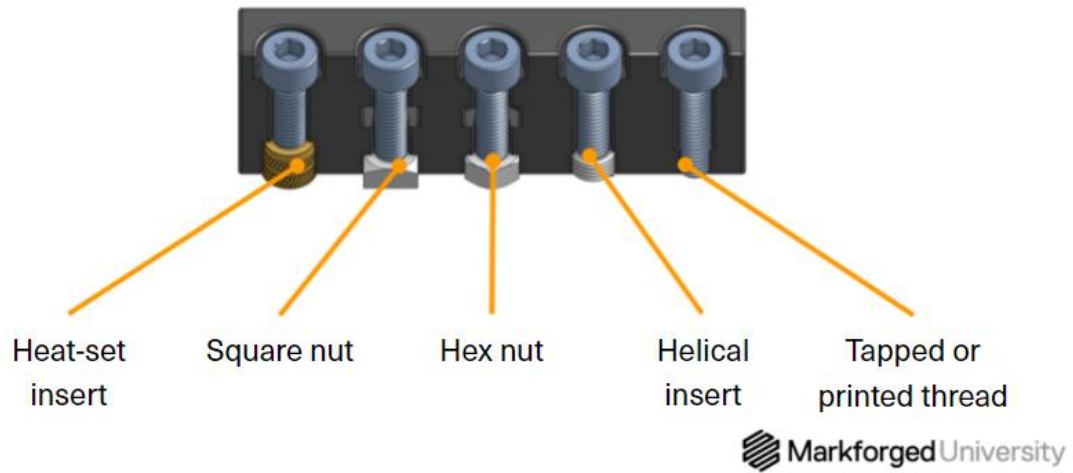
- **Adding Threaded Features**

## Types of Threaded Features



- **Threaded Features**

## Types of Threaded Features



- Several types.

## Comparing Different Types of Threads



← Increasing pull-out strength

- **Threaded Features**
  - Right is de weakest solution.

## Heat Set Inserts



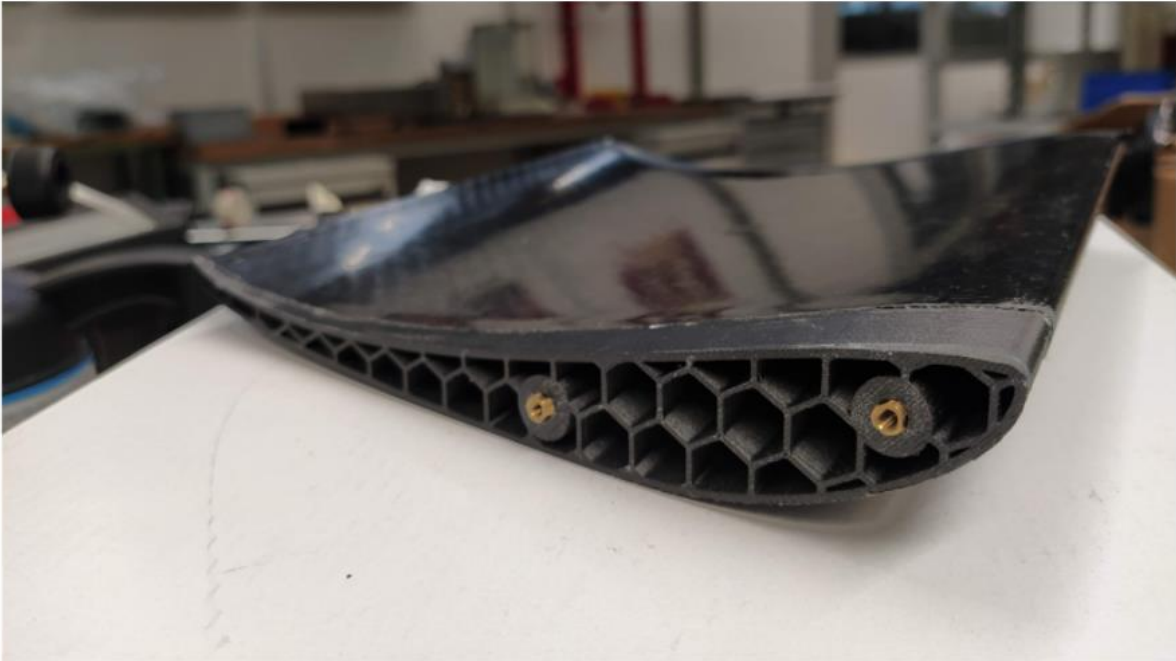
- **Heat Set Inserts**

## Heat Set Inserts

Easily melted into a part with an inexpensive soldering iron and a correctly sized installation tip

High pull-out strength, when installed on opposite side of part as bolt





- **Example: AMC Racing Sidepod Wing**







Captive Square or Hex Nuts



- **Captive Square or Hex Nuts**

- Captive = opgesloten
- Cavity = holte

☰ C3.2 - Incorporating Hardware Into Composite Parts RESOURCES

## Captive Pockets Retain Nuts





- **Captive Pockets Retain Nuts**

- Retain = behouden.


☰ C3.2 - Incorporating Hardware Into Composite Parts RESOURCES


## Coiled Helical Inserts

Increased wear resistance

Not a huge increase in pull-out strength

Lowest cross-sectional profile





- **Threaded Features – Helical Inserts**

- Not recommended.

## Captive Hardware through Overprinting



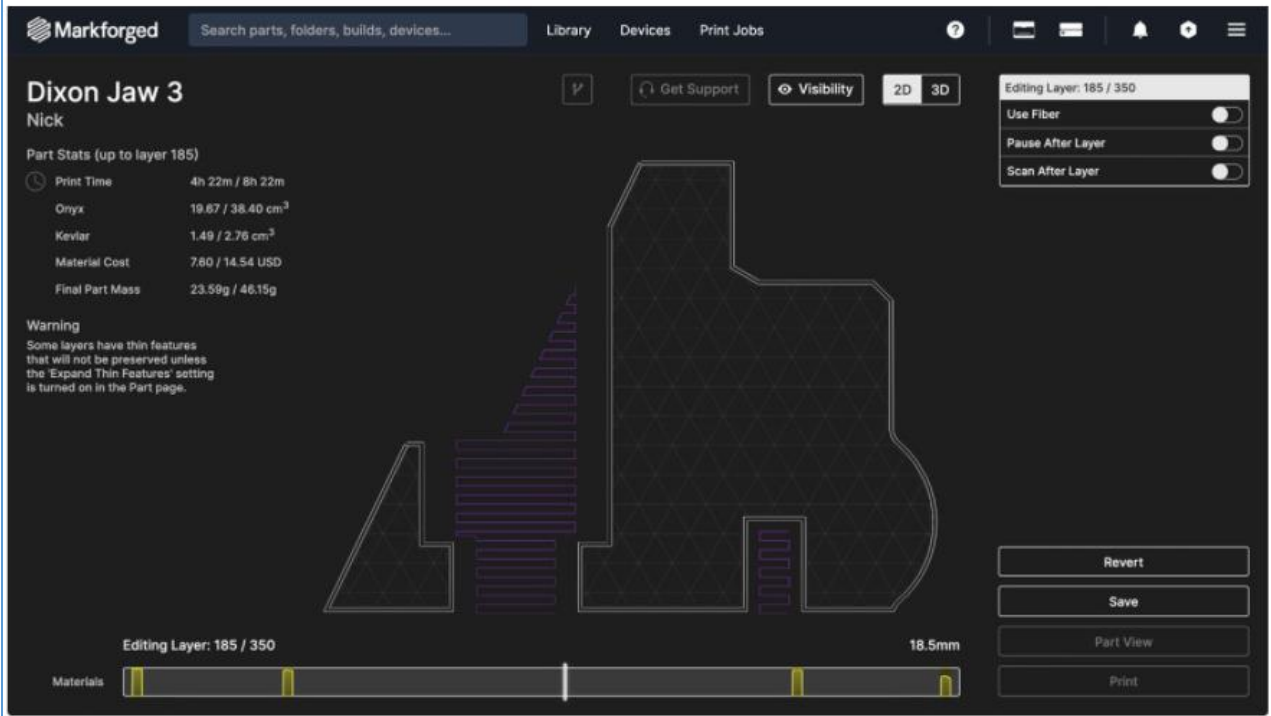
- **Captive Hardware through Overprinting**

## The Overprinting Process

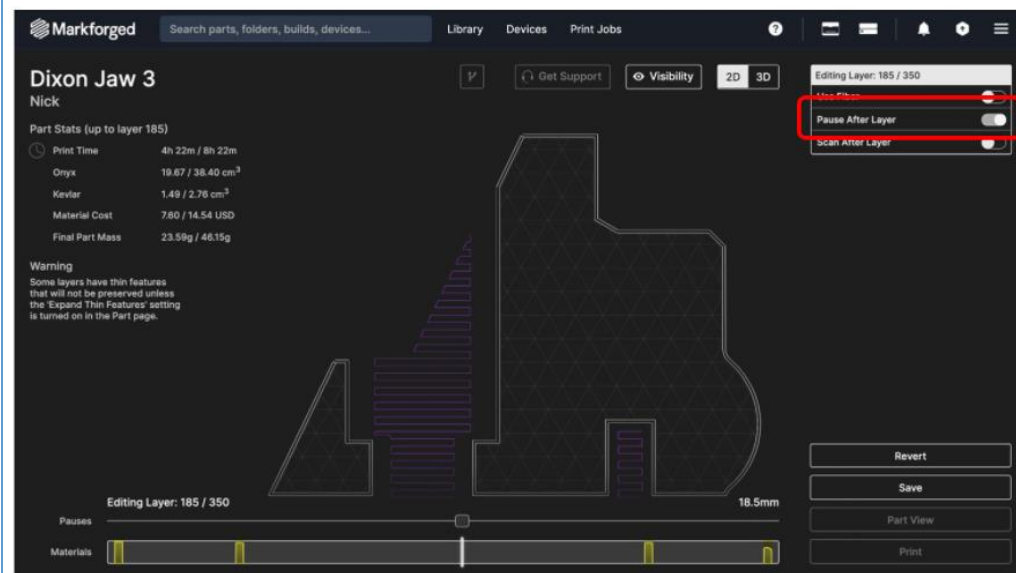
- Design negative space into part
- Pause mid-print
- Remove support material
- Insert hardware and resume
- Hardware is captured inside part



- **Overprinting Process**



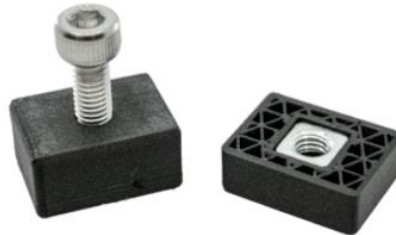
- Pause in Layer editor



- The printer will automatically pause the printer and sends an e-mail.

## The Overprinting Process

- Design negative space into part
- Pause mid-print
- Remove support material
- Insert hardware and resume
- Hardware is captured inside part



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- Remove support material.
- Then add the inserts by using a little bit of the glue stick just at the top of the insert and at the metal part, because onyx will stick to the model otherwise.
- It is also important not apply glue on the axis infill the part. That will disrob the layer bounding and create weakness in the part.

## Pros and Cons of Overprinting

### Pros

- Captive hardware reduces risk of stray parts
- Clean design

### Cons

- Risk of print head collision
- Requires operator supervision to resume from pause



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- **Pros and Cons of Overprinting**



- Stray parts = verdwaalde / zoekgeraakte (of the shelf) onderdelen?
- Supervision is required to resume (hervatten): If you leave the printer pauses to long (more than 30 à 60 minutes) the chamber of the part will cool out, witch result in a weaker bound between the layer where paused at and the next layer. > Risk of failure of the application.

☰ C3.2 - Incorporating Hardware Into Composite Parts RESOURCES

## Printed or Tapped Threads

**AVOID PRINTED THREADS WHEREVER POSSIBLE**


Only can achieve nylon thread pullout strength (usually weaker)

Best printed with axial direction in Z-axis

Print thread sizes larger than M3 or #8

Only good for single installation without removal


**REMINDER: AVOID PRINTED THREADS WHEREVER POSSIBLE**

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- **Printed or Tapped Threads**

### Threaded Features Comparison

	Heat-set	Square Nut	Hex Nut	Embedded	Helical	Printed
Pull-out strength	+++	++	++	++	+	+
Torque-out strength	++	+++	++	++	+	+
Small profile	++	+	++	++	+++	+++
Ease of installation	++	+++	+++	+	++	+++

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- Threaded Features Comparison

☰ C3.2 - Incorporating Hardware Into Composite Parts RESOURCES



## Module Review

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- Module Review

Which of the following provides the highest pull-out strength threaded features among the option listed.

- Printed thread
- Tapped thread
- Coiled helical insert
- Square nut

When attempting to add wear resistance to a flat surface of a part, we want to design in dowel pins to add a harder wear surface over a large contact area.

- True
- False

Adding off-the-shelf hardware to a 3D printed part should be driven by:

- Lack of access to a CNC machine
- Part functional requirements
- The skill of the 3D printer operator
- A whim




### Results

Your Score: 100% (30 points)

Passing Score: 80% (24 points)

---

### Result:

 Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

### C3.3 – Optimizing Composite Supports Through Design

☰ C3.3 - Optimizing Composite Supports Through Design RESOURCES



Markforged University – Advanced Composites

## Optimizing Composite Support Structures Through Design

- **Optimizing Composite Support Structures Through Design**
  - Samengestelde draagconstructies optimaliseren door middel van ontwerp.

## Module Overview

Supports in Review

Eliminating Supports with Chamfers

Leveraging the 'Supports Angle' Feature

Splitting Supports into Regions

Supporting High Angle Surfaces

Solidifying Trusses

DIY Supports for Stability

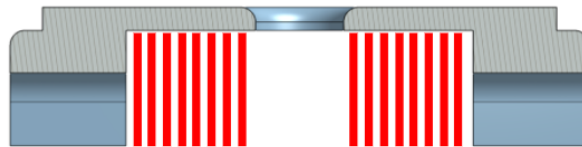


- **Module Overview**

- Ondersteuning in beoordeling.
- Het elimineren van steunen door met afschuiningen te werken.
- Gebruikmakend van de functie 'ondersteuningshoek'.
- Ondersteuning opsplitsen in regio's.
- Ondersteunende hoge hoek oppervlakken.
- Stollende spanten.
- DIY-ondersteuning voor stabiliteit (Do It Yourself)



## Review: What are Supports?



- 3D prints are built layer by layer on **top** of the preceding layer
- Cantilevered or overhanging features may be built on top of **supports**

- **Review: What are Supports?**

- Cantilevered = vrijdragend

## Review: What's Wrong With Supports?



Wasted Material Cost



Additional Print Time



Labor Cost for Removal

- **Review: What's Wrong With Supports?**

## It's a Balance



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- **It's a Balance**

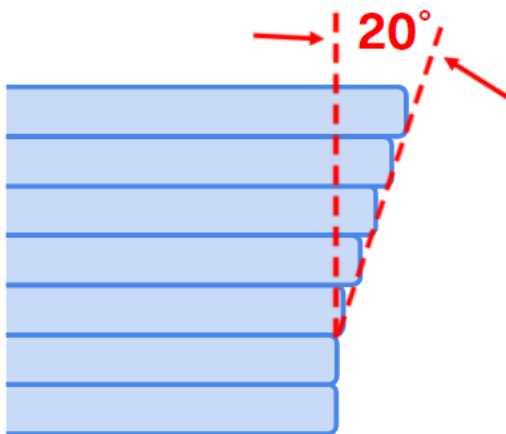
### THEME

Optimize supports by minimizing their presence and maximizing their removability

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- **What Does Optimizing Supports Really Mean?**

## Review: The 45° Rule to Minimize Supports



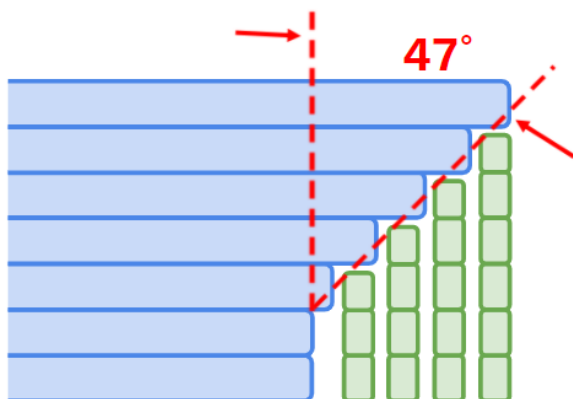
Overhanging features are printed with each layer **projecting out** past the layer beneath it

At angles  $<45^\circ$  from the vertical, each new layer is supported enough to print **without sagging or part surface defects**



- **Review: The 45° Rule to Minimize Supports**
  - Sagging = doorzakken.

## Review: The 45° Rule to Minimize Supports



At  $>45^\circ$  from the vertical, each new layer projects too far to self-support

Support material is automatically generated in software to maintain part quality



STRATEGY  
Minimize supports by  
reducing overhang angles to  $<45^\circ$



- **Principal Strategy: Reduce Overhanging Angles to  $<45^\circ$**

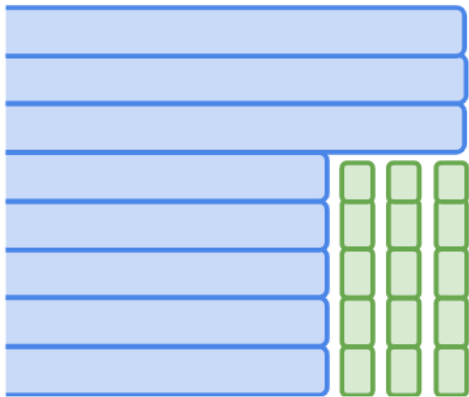


Eliminating Supports with Chamfers



- **Eliminating Support with Chamfers**

## Cantilevered features will generate supports...

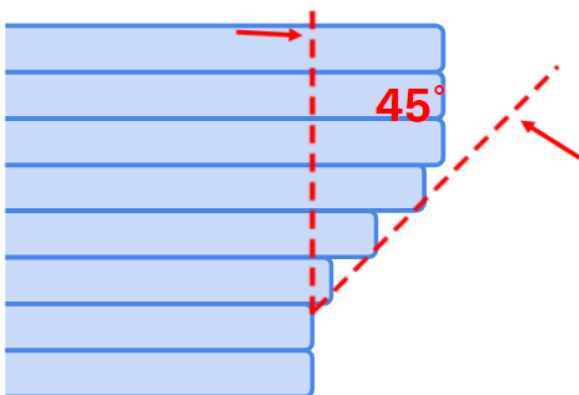


Cantilevered features are 90° from vertical  
Feature's position in Z-axis determines additional time/cost to support feature  
45° chamfer to edge of feature to eliminate supports



- **Cantilevered Features Generate Supports**

## ...but chamfering them eliminates supports

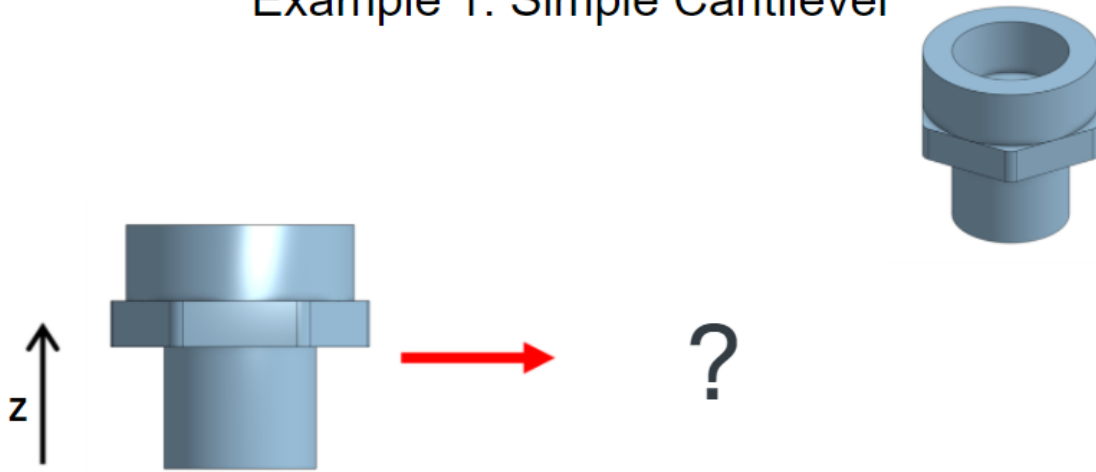


45° chamfer completely eliminates supports on overhanging features



- A Solution.

### Example 1: Simple Cantilever



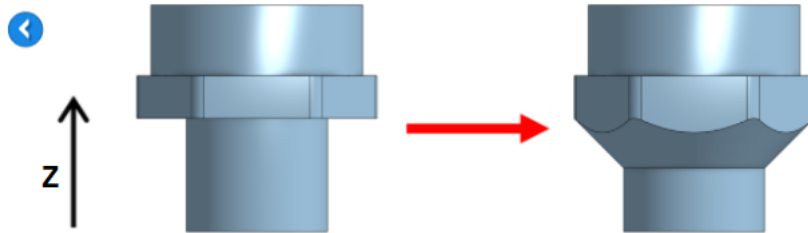
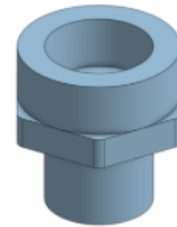
Show Answer

- Example 1

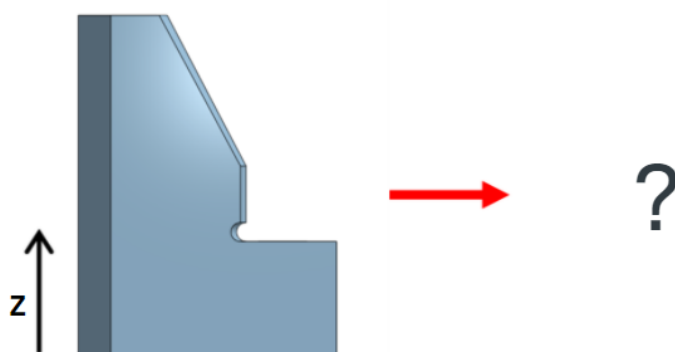
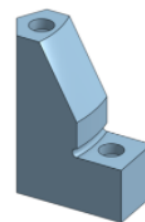


### Example 1: Simple Cantilever

**Note:** making a re-design like this is obviously dependent on it not interfering with other geometry this part may interface with.



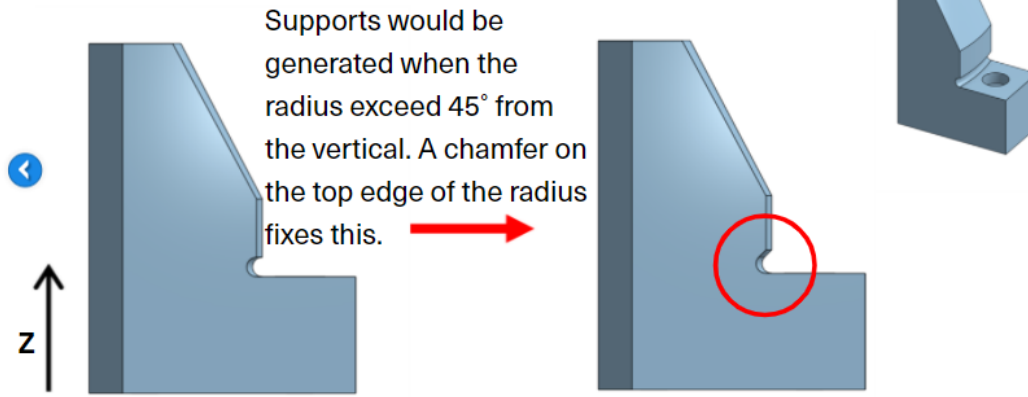
### Example 2: Overhanging Radii



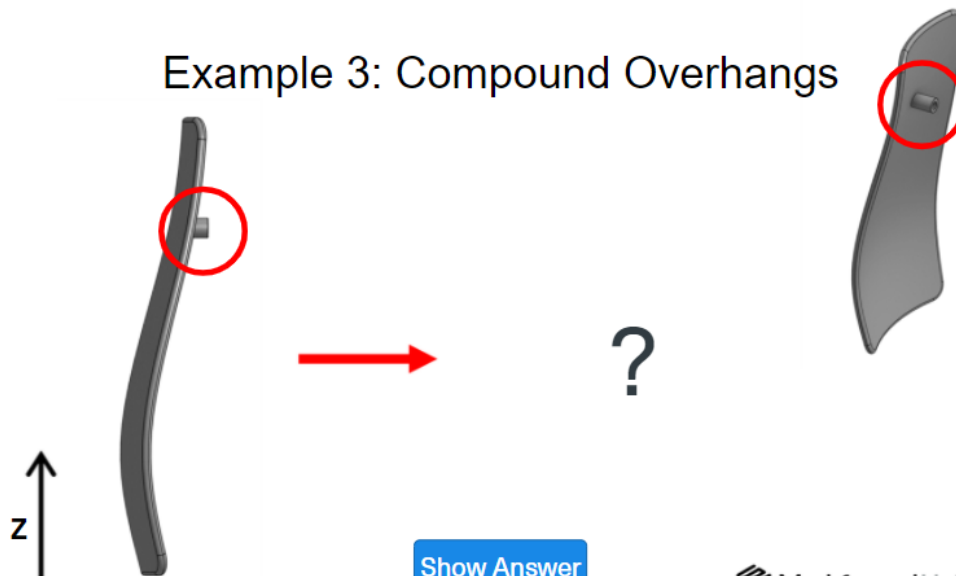
Show Answer

- Example 2

### Example 2: Overhanging Radii



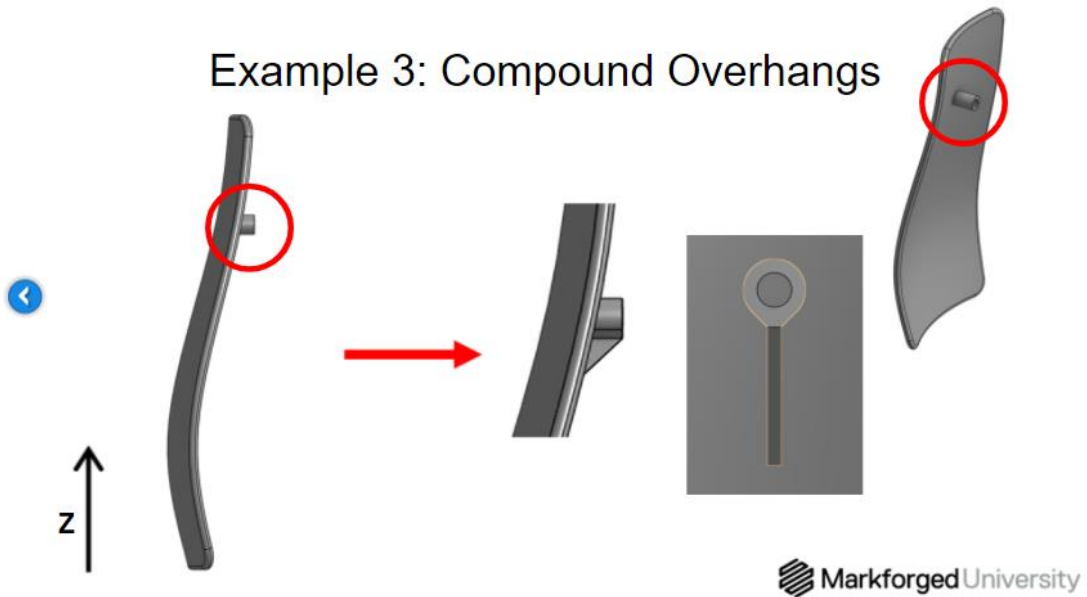
### Example 3: Compound Overhangs



Show Answer

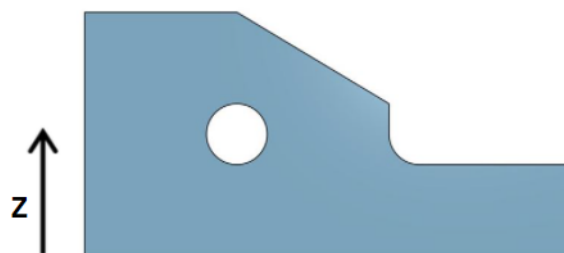
- Example 3

### Example 3: Compound Overhangs



- Solution in 2 directions.

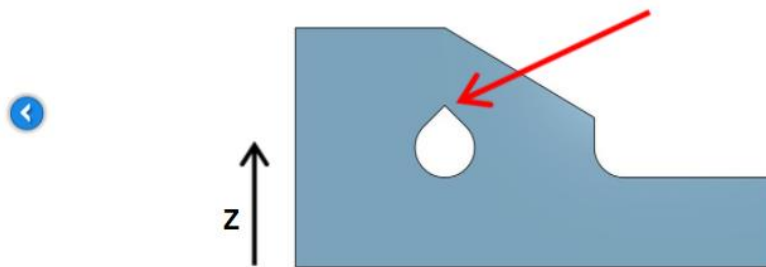
### Example 4: Horizontal Holes



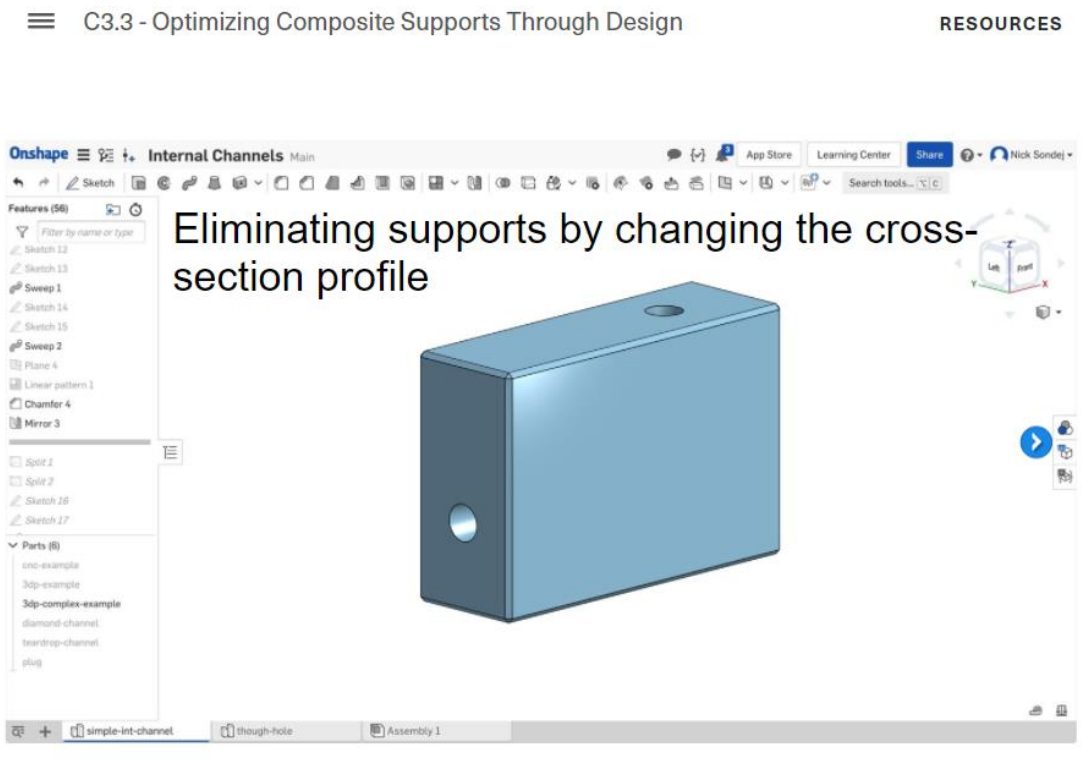
Show Answer

- Example 4

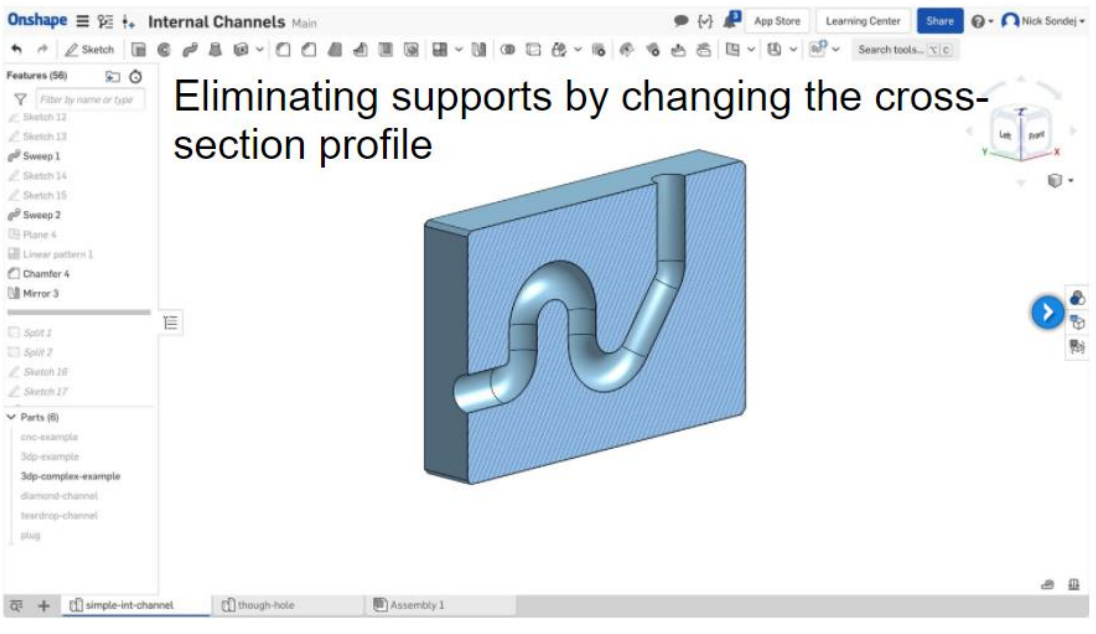
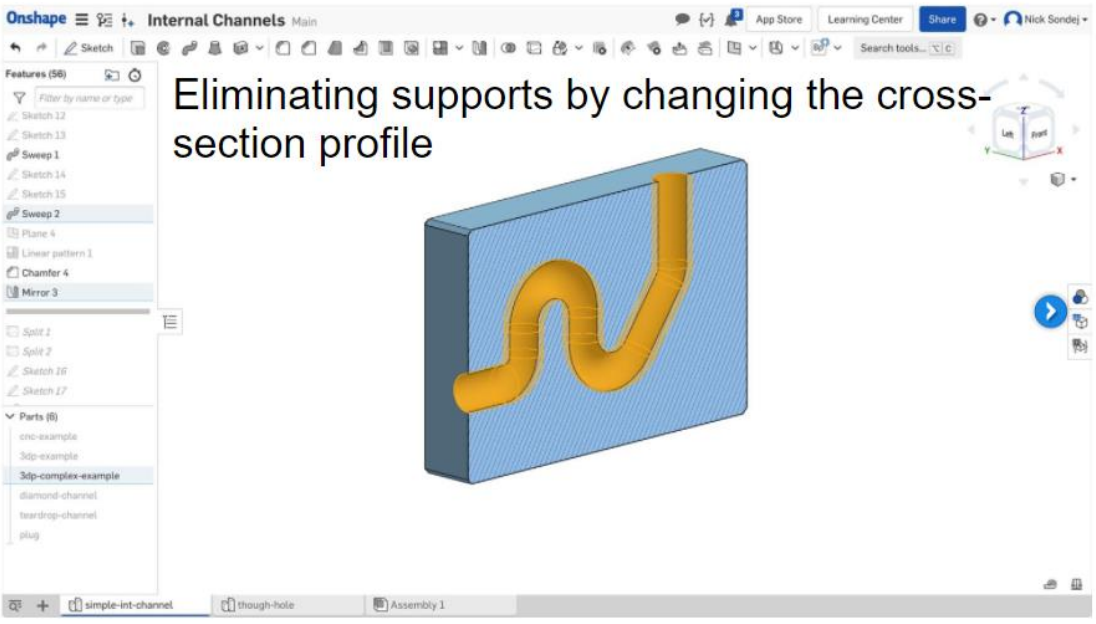
### Example 4: Horizontal Holes

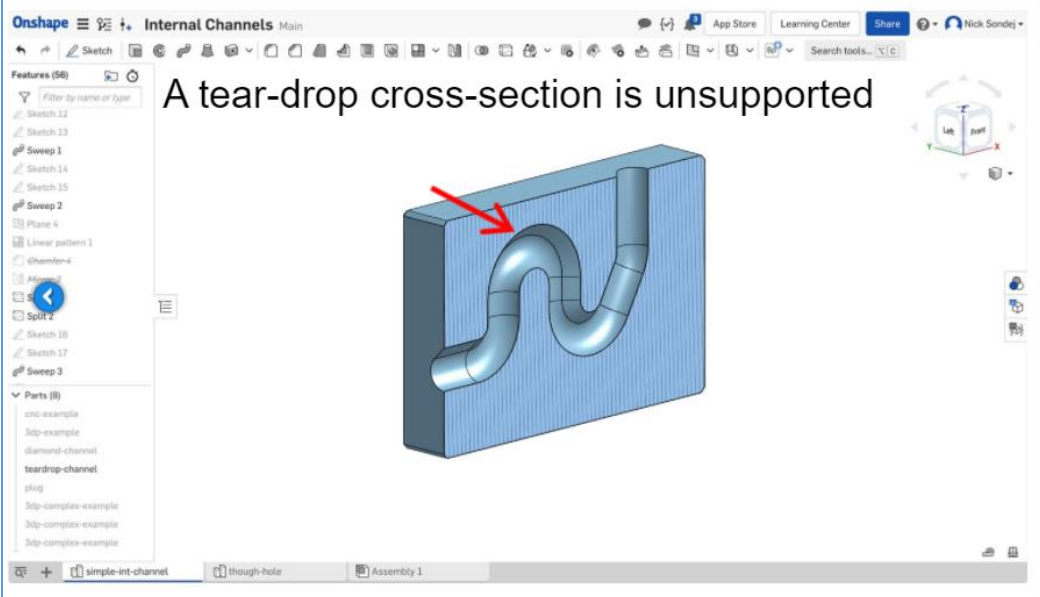
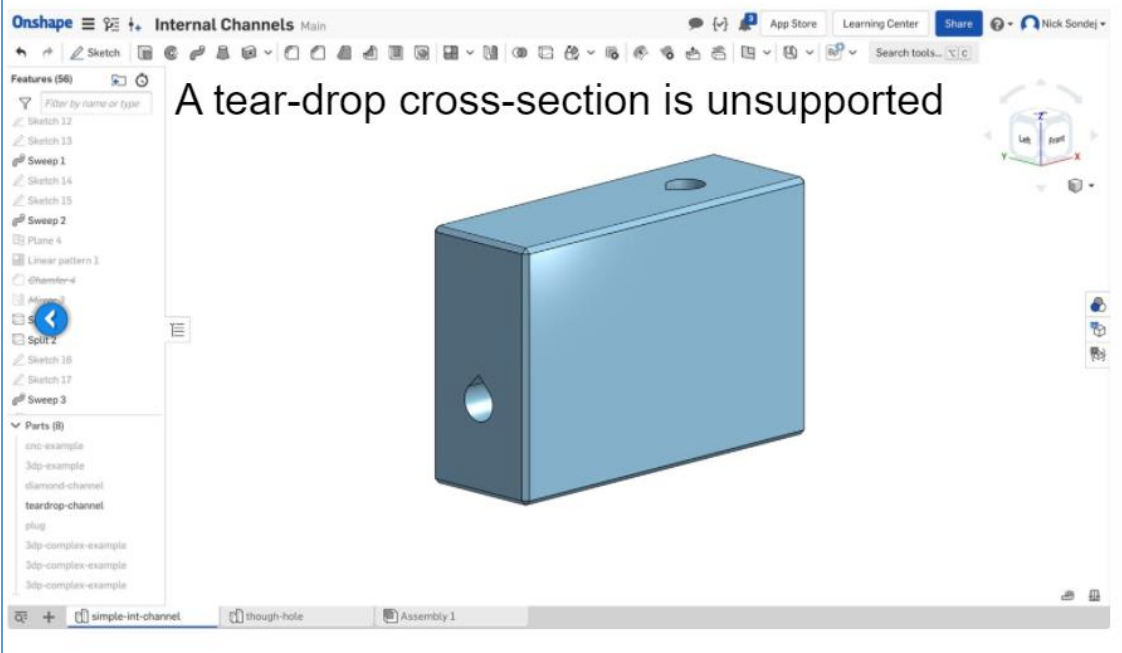


- Solution by teardrop shape

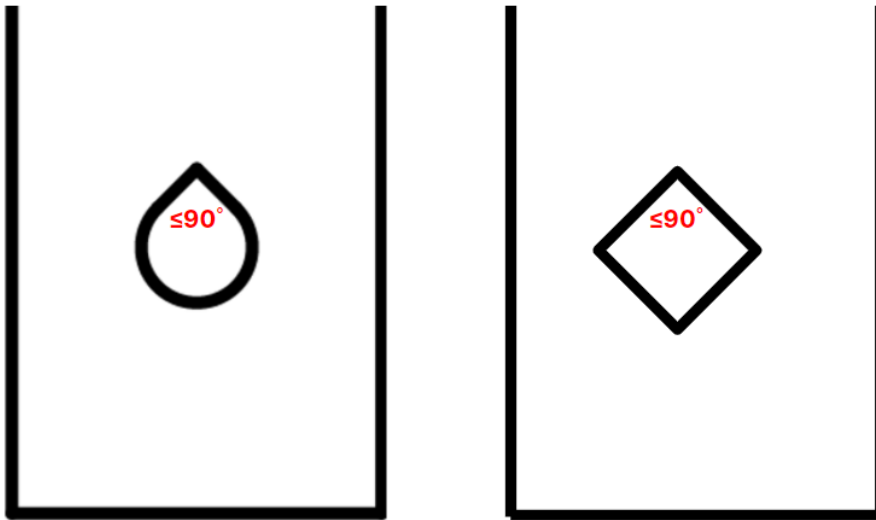


- Why is a Hole Round?

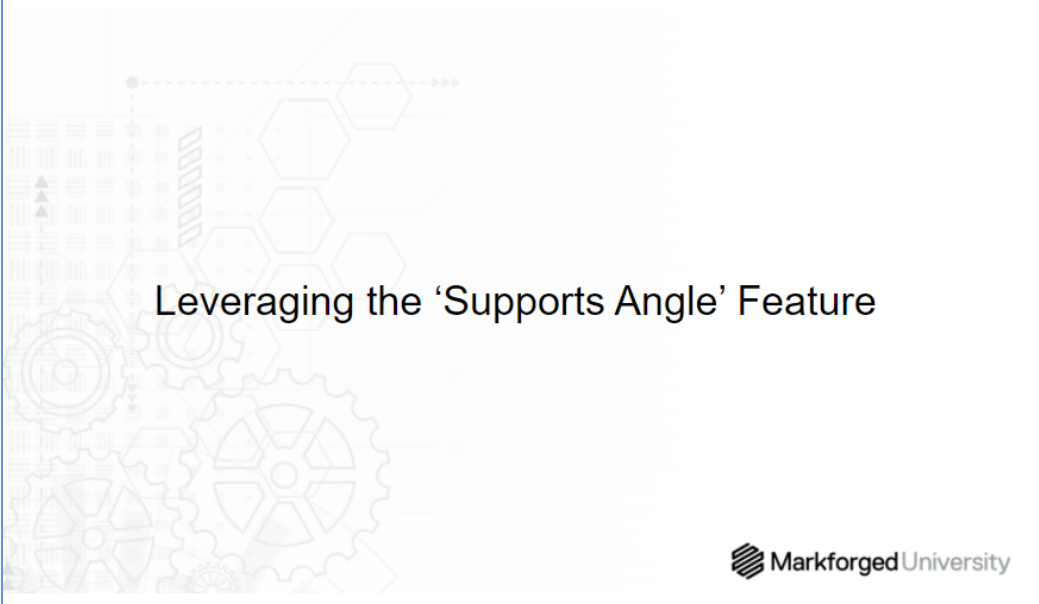








- **Different Profile Options**



- **Leveraging the 'Support Angle' Feature**
  - Gebruikmaken van de functie 'Ondersteuningshoek'

## Supports Have a Principal Direction



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- **Supports Have a Principal Direction**
  - Steunen hebben een hoofdrichting.

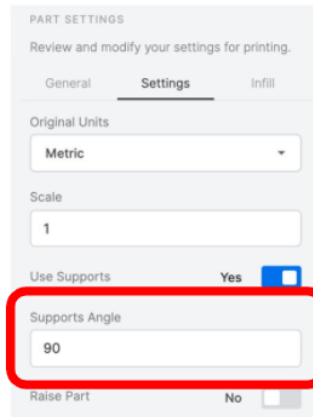
## Supports Have a Principal Direction



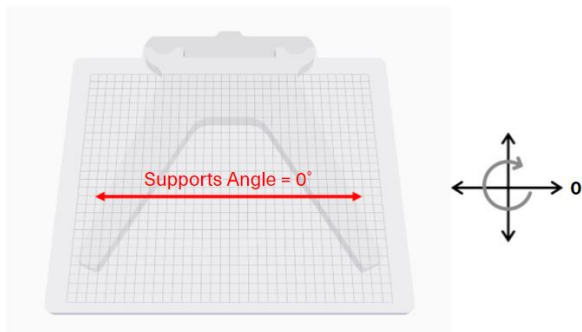
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- How this pattern is oriented can have an impact how easy or difficult on different reasons are to remove.

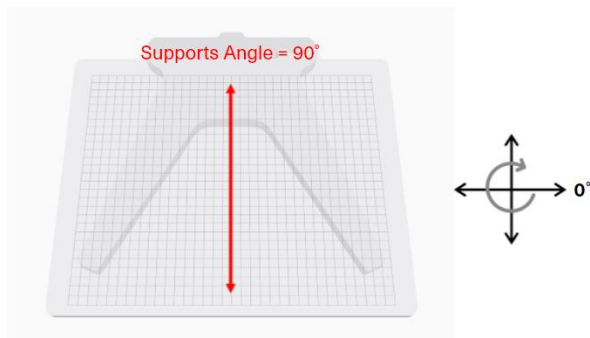
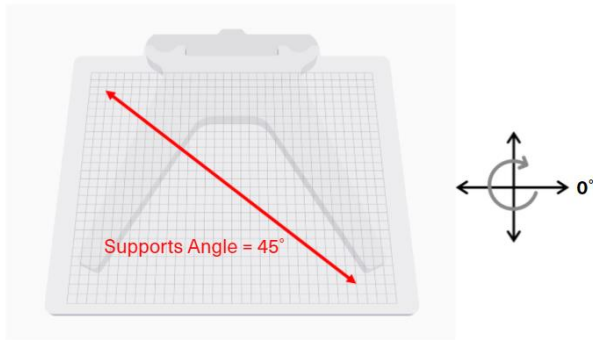
## Principal Direction Measured as 'Supports Angle'



### ○ Support Angle Feature.



- **The Supports Angle and the Print Bed**





## Why does it matter?

Supports can break at the U-turn during removal and cause difficulties

Choosing optimal Supports Angle will make post-processing life easier



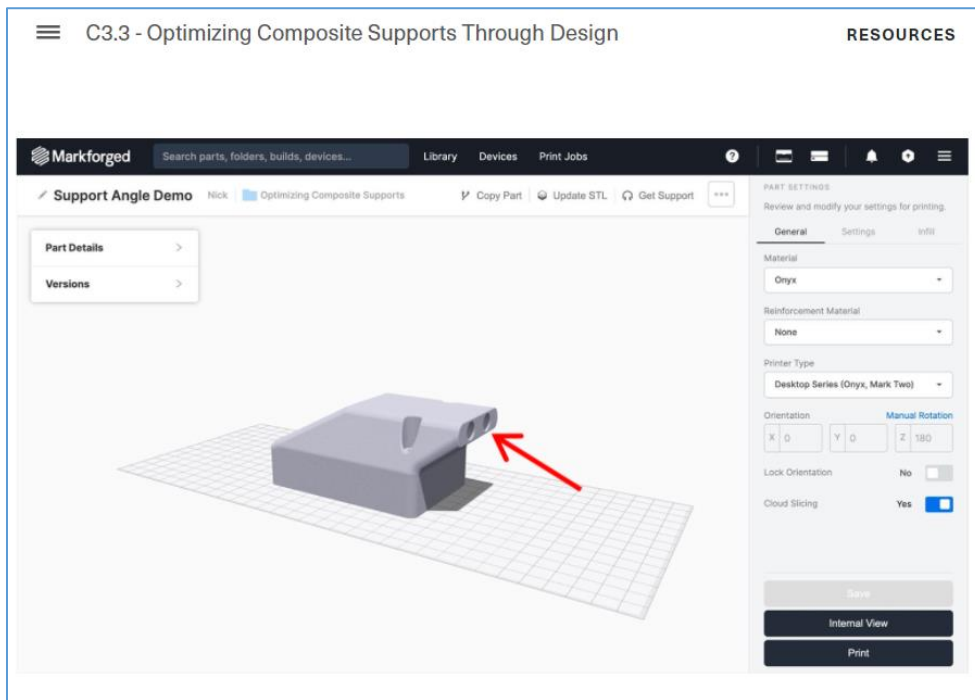
- **Why does it matter?**

## STRATEGY

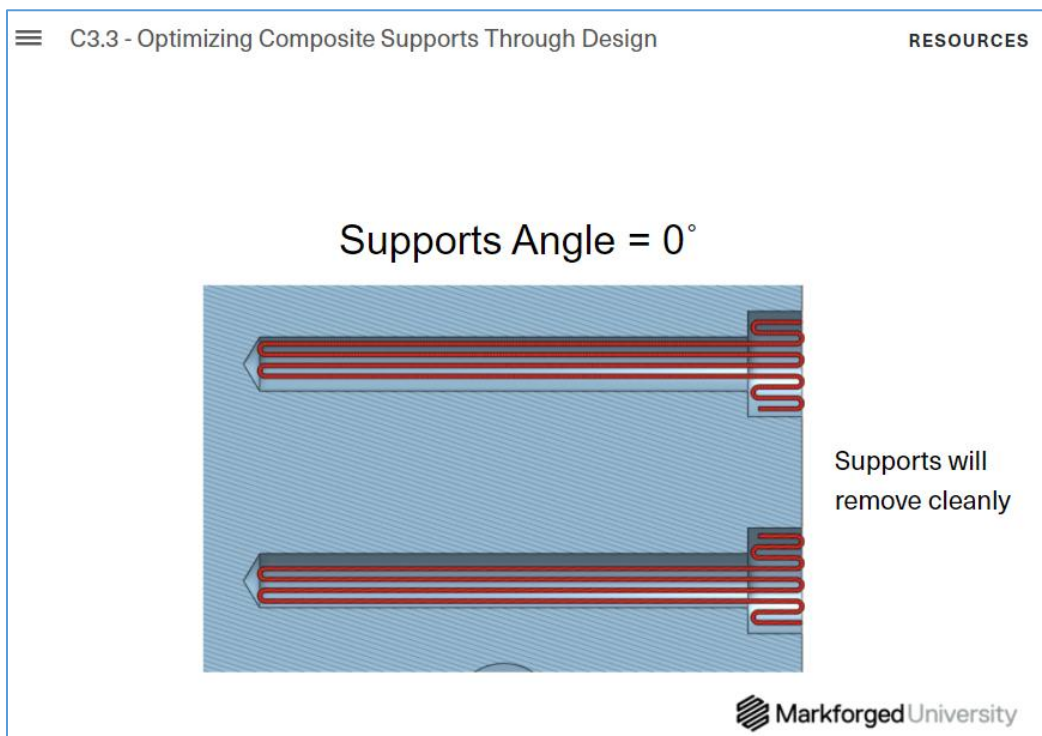
Align supports axially to deep horizontal features with Supports Angle



- **Strategy: Align Supports Axial to Holes.**



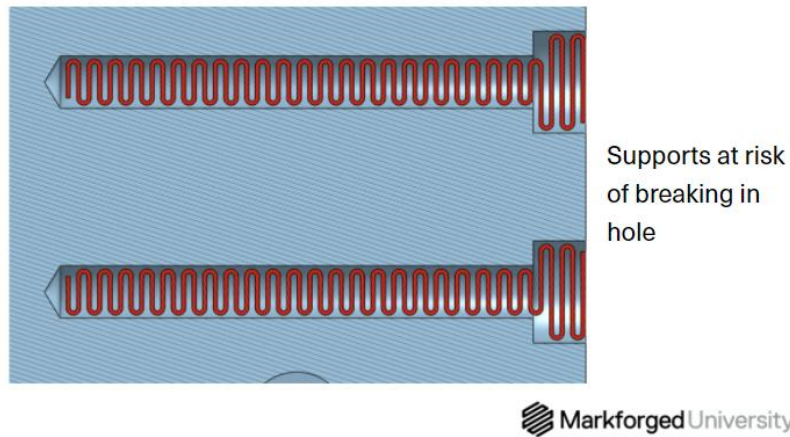
- **Example: Deep Horizontal Bores**



- **Supports Angle = 0°**
  - U-turn horizontal.
  - Easy to remove,.



### Supports Angle = 90°

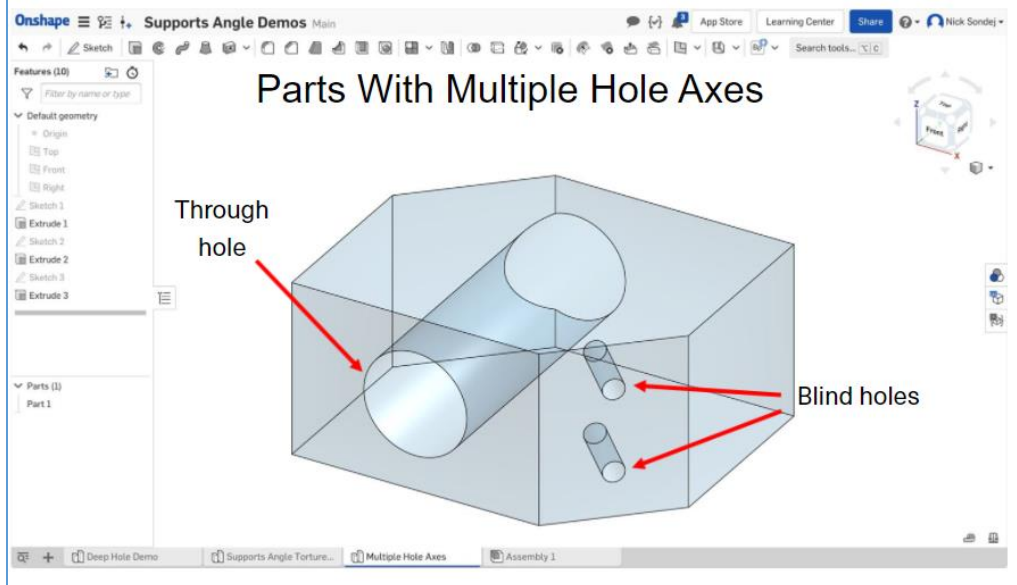


- **Supports Angle = 90°**
  - U-turn horizontal.
  - Hard to remove.

### Look at the Difference

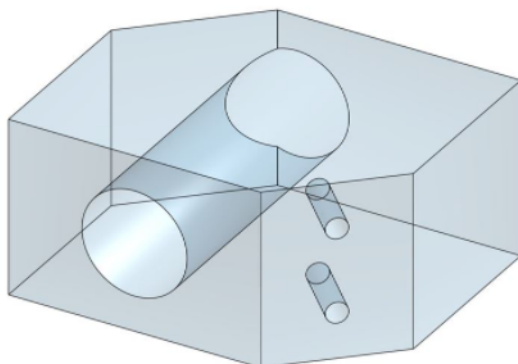


- **Look at the Difference**



- **Parts With Multiple Hole Axes**

## Align Supports Angle with Problematic Features



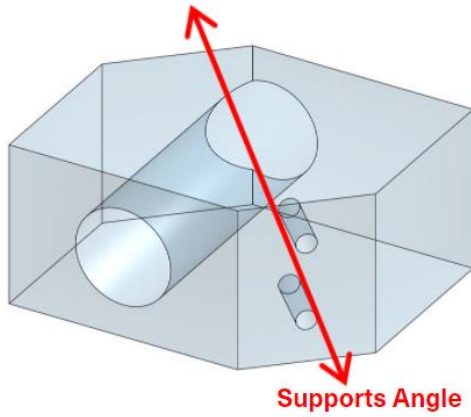
Supports in through-hole can be easily pressed out

Smaller blind holes can be problematic to remove supports from

Align Supports Angle with blind holes in this example

- **Align Supports Angle with Problematic Features**

## Align Supports Angle with Problematic Features



Supports in through-hole can be easily pressed out

Smaller blind holes can be problematic to remove supports from

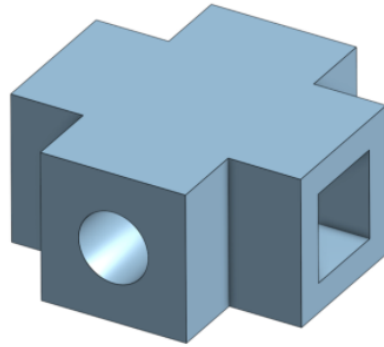
Align Supports Angle with blind holes in this example



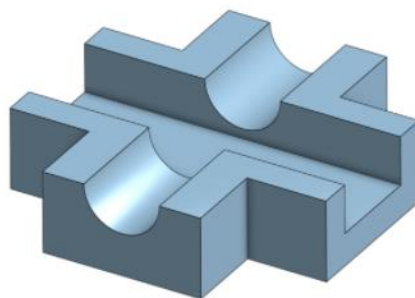
## Improving Support Removal By Breaking Up Regions



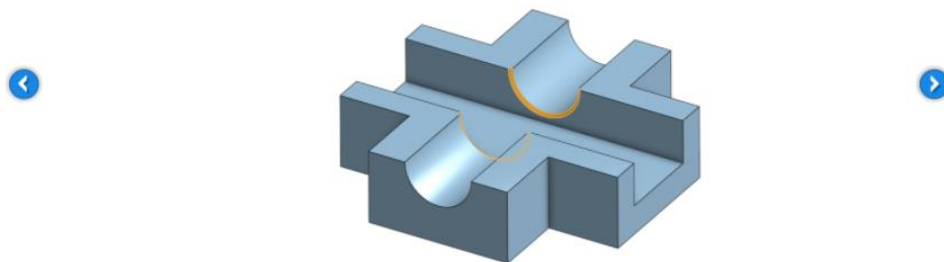
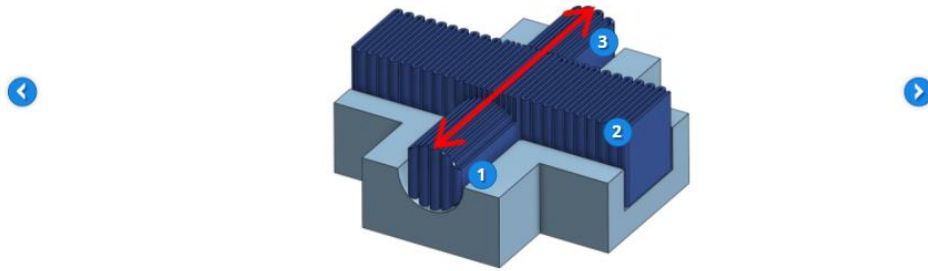
- **Improving Support Removal By Breaking Up Regions**



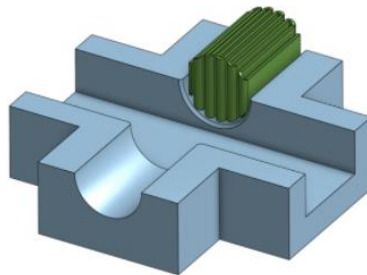
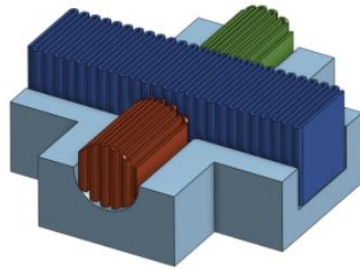
- **CAD Example**



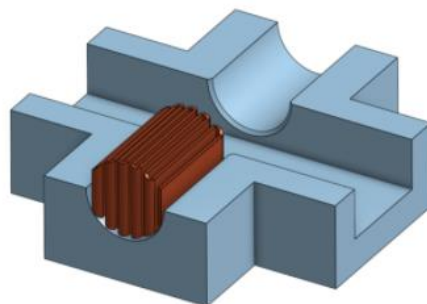
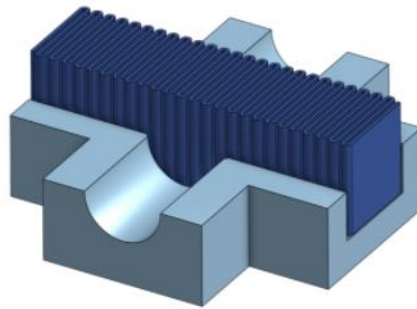
- One circular bore and on square.
- The diameter of the bore does not extend all the way the bottom of the square one.

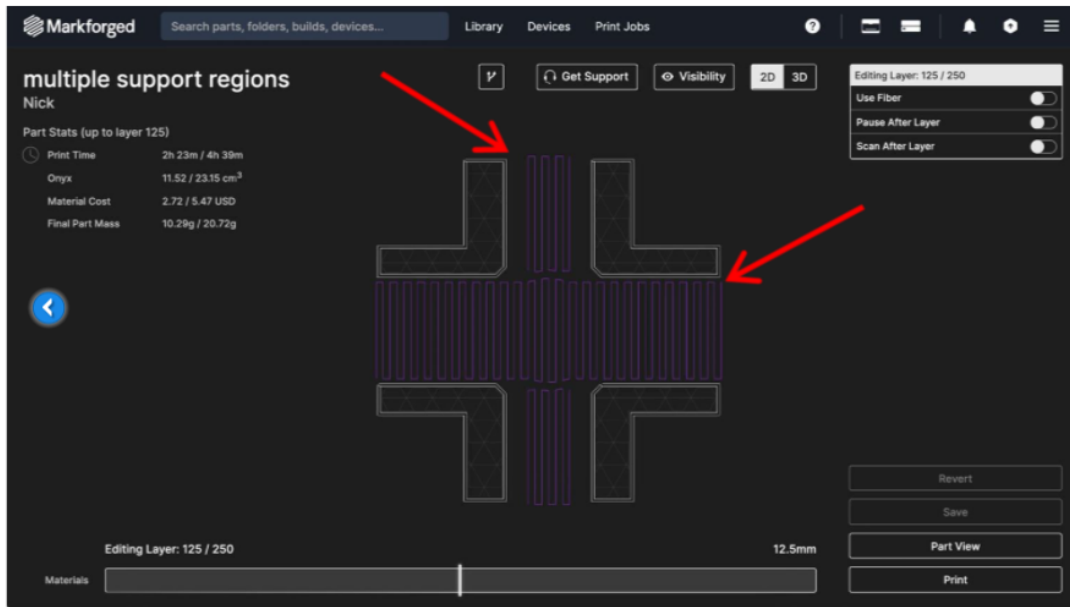


- Using chamfers will be the key to the solution.







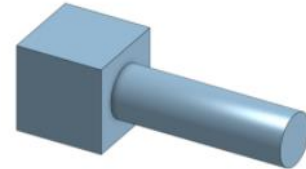


- Realized by using the chamfers.



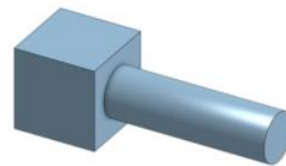
- **Supporting High Angle Surfaces**

## What's a High Angle Surface?



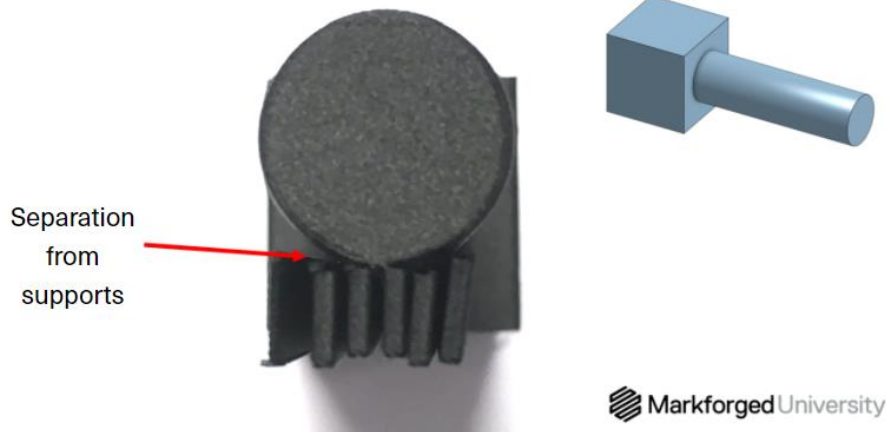
- **What's a High Angle Surface?**

## What's a High Angle Surface?



- Pretty close to horizontal, but not quit.

## What's a High Angle Surface?



- Reduced part quality and increased surface defects.

## The Issue with High Angle Surfaces

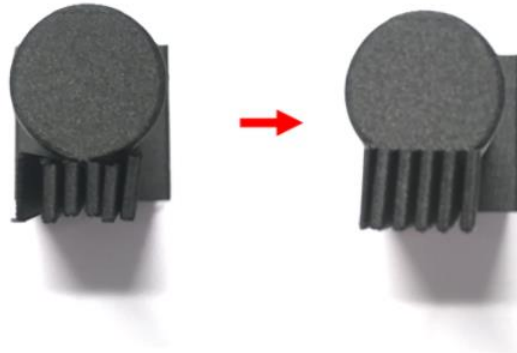


High angle surfaces often exhibit surface defects

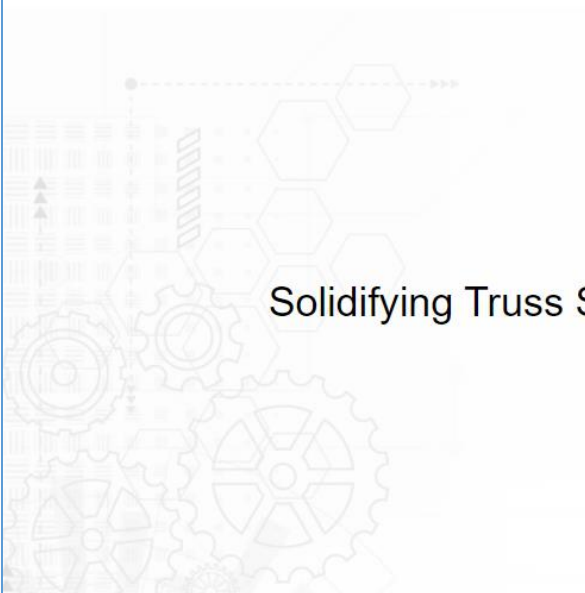
Floors tend to peel off from supports

- **The Issue with High Angle Surfaces**

- Exhibit = vertonen
- Tend = de neiging tot.

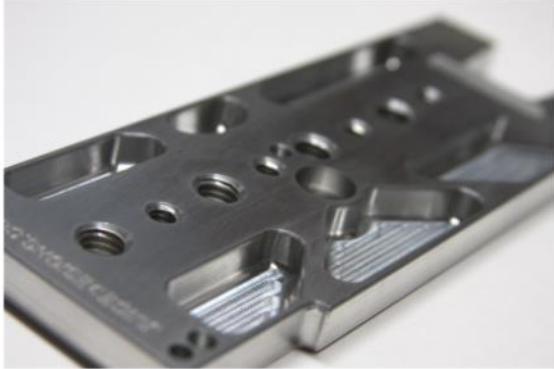


- **A potential Fix**



- **Solidifying Truss Structures**
  - Solidifying = verharden

## Solidify Lightning Pockets



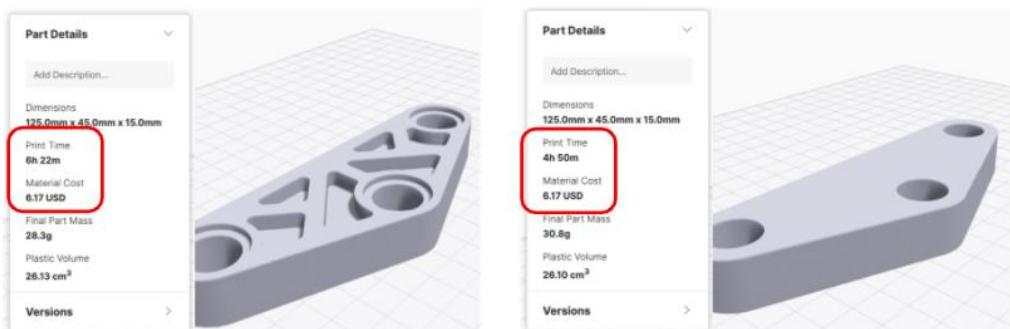
Maximize stiffness to weight with subtractive processes

AM offers us ability to produce more complex, lighter structures



- **Lightening Pockets**
  - Subtractive = onttrekkend

## Spot the Difference



- **Spot the Difference**



- In case of a feature that was previously designed for machining. The right one requires less print time and is more solid. It turns out that the support structures of the left are unnecessary.

☰ C3.3 - Optimizing Composite Supports Through Design RESOURCES



## Do-it-Yourself (DIY) Supports


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- **DIY Supports**

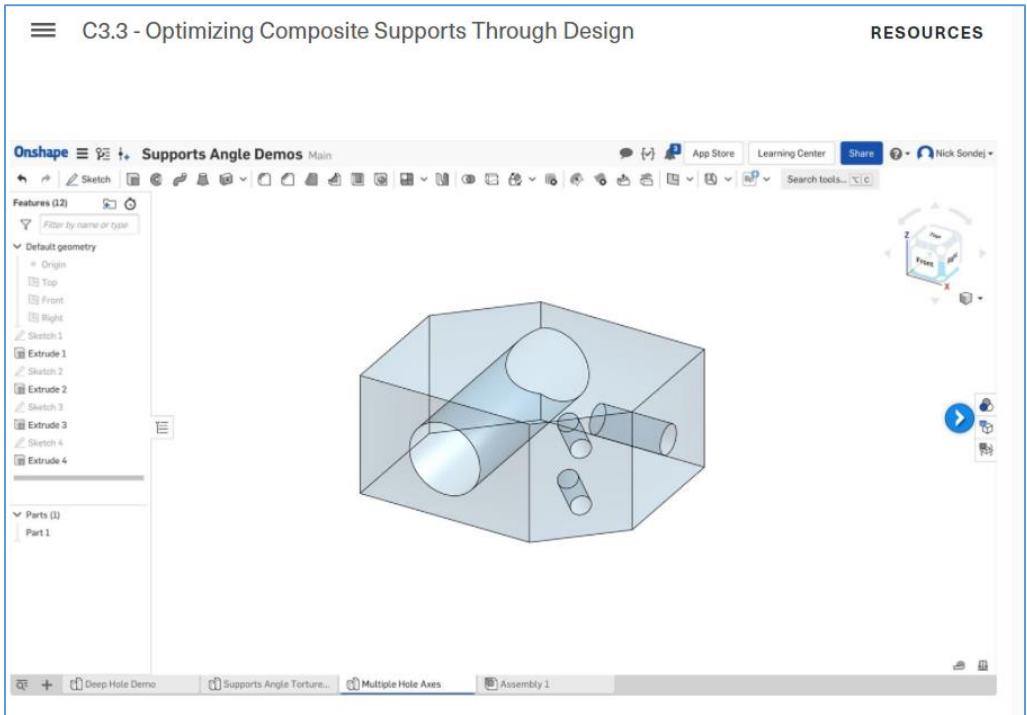
☰ C3.3 - Optimizing Composite Supports Through Design RESOURCES

STRATEGY

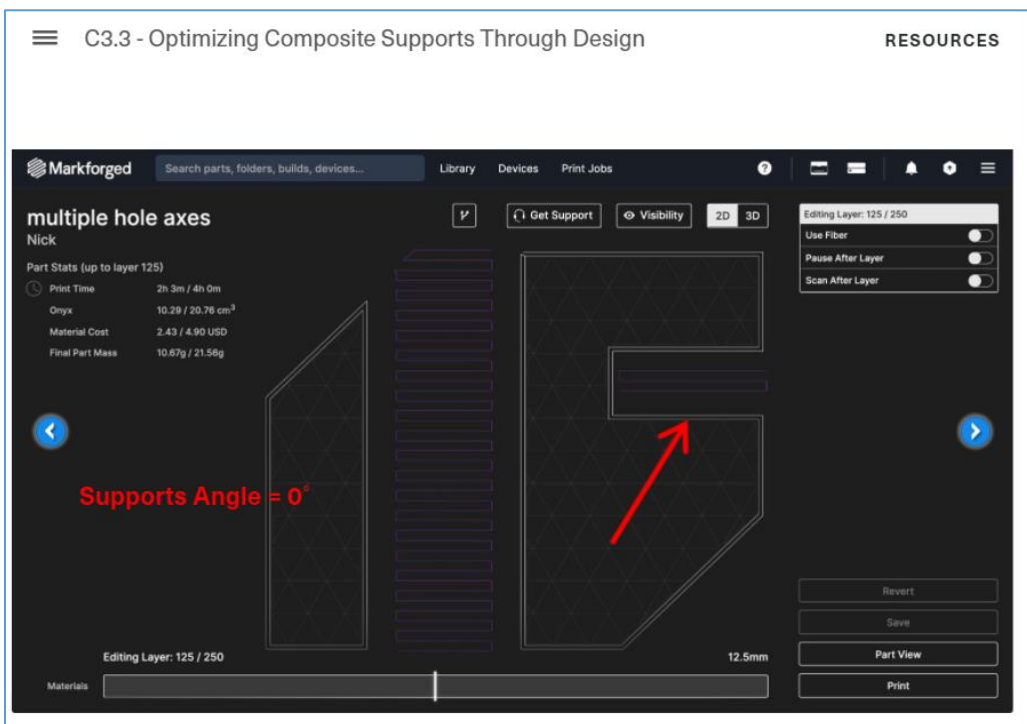
## CAD in your own supports when the supports generated by Eiger are inefficient

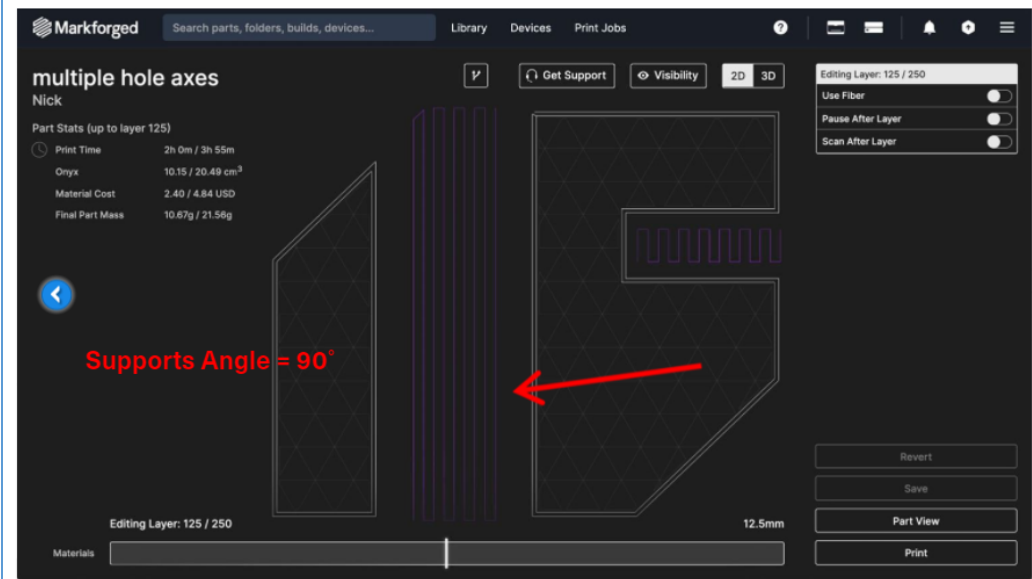
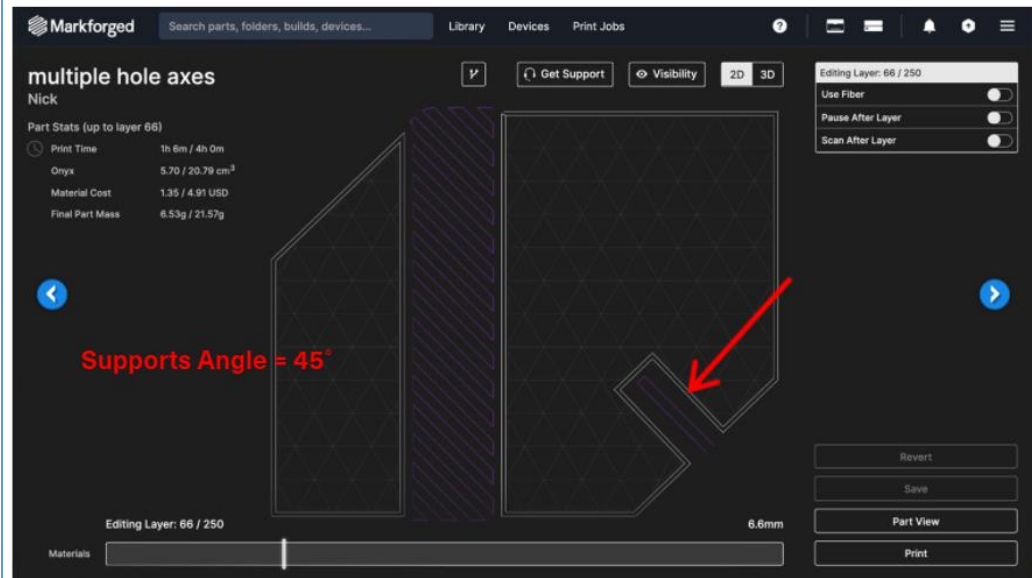
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- **Strategy: Design Your Own Supports**



- **Example: DIY Supports**



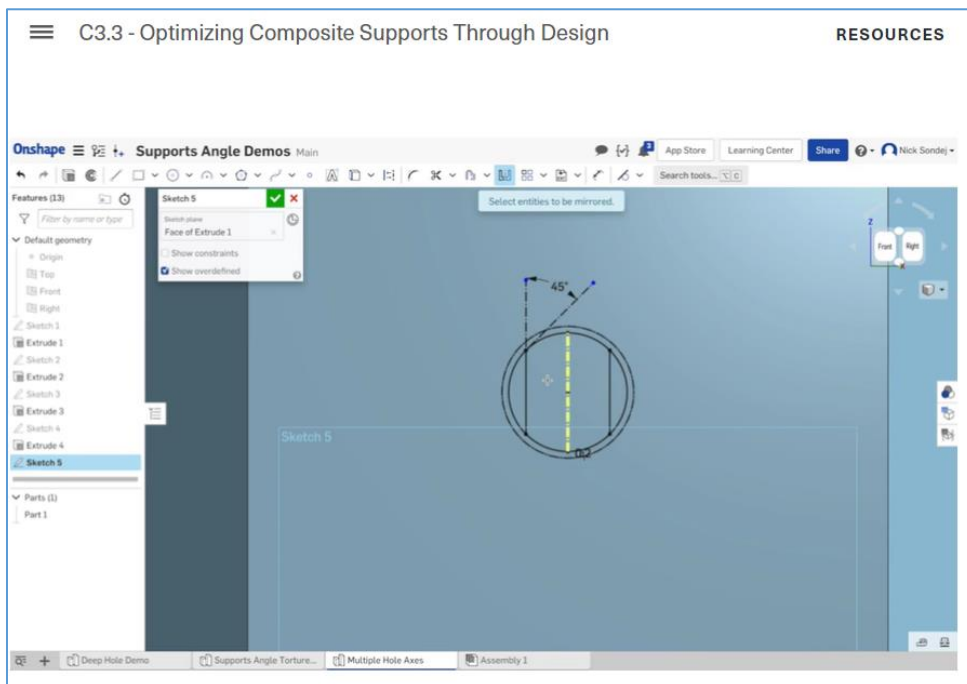


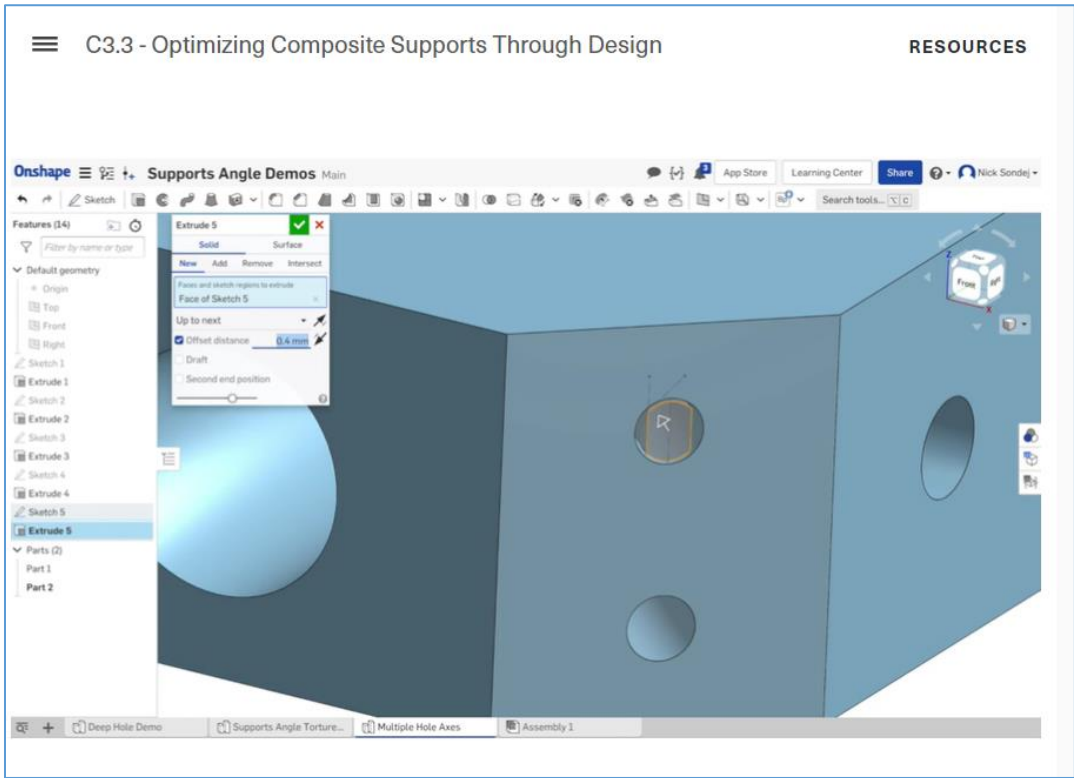
## The Solution? Design Your Own

Start Video

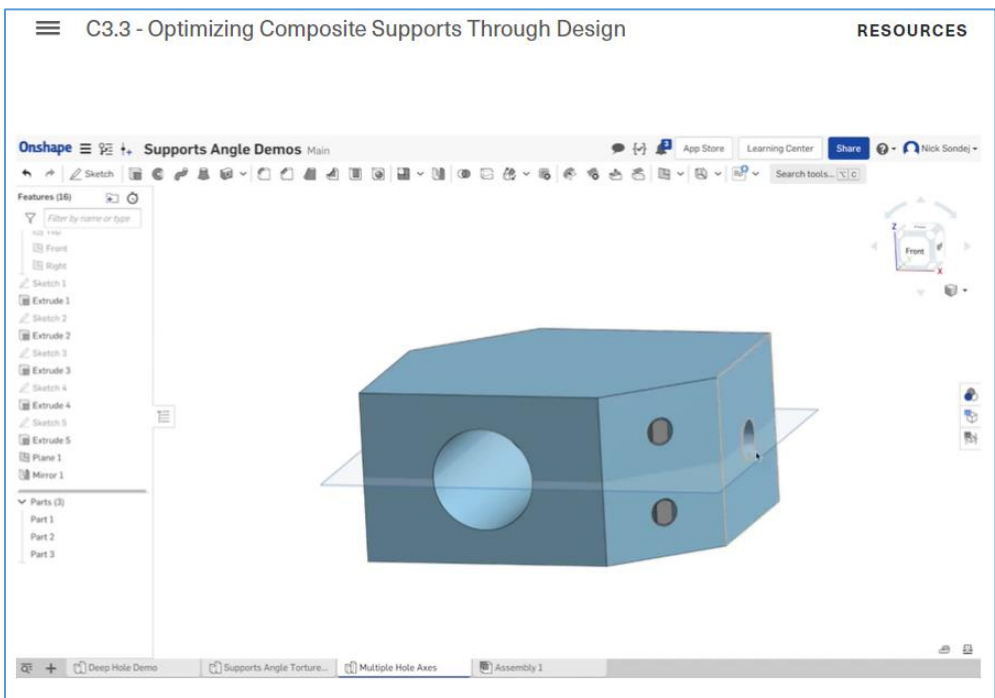


- **Video: Designing Your Own Supports**

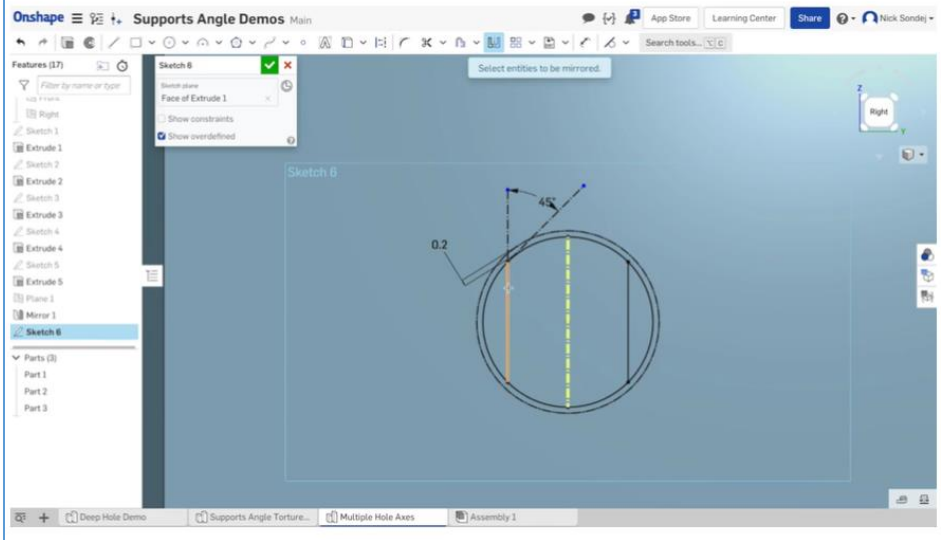
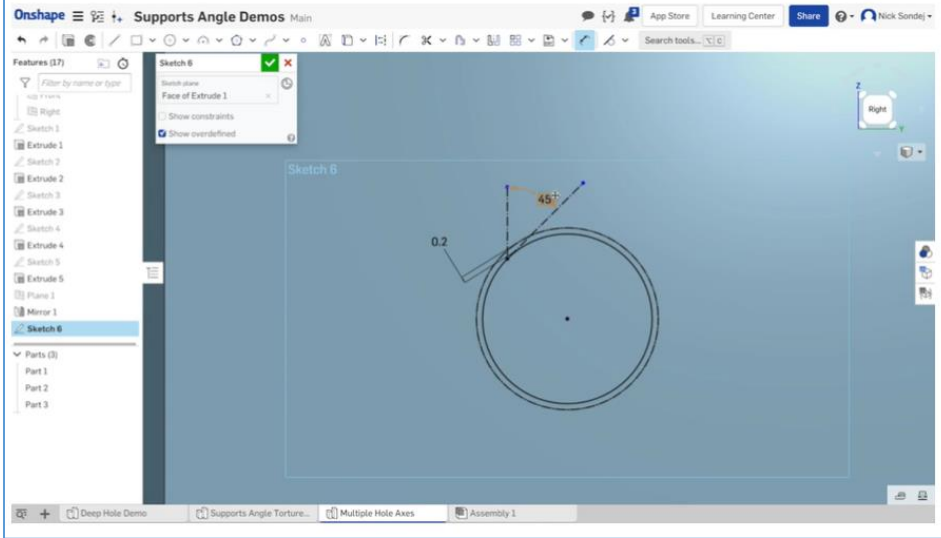




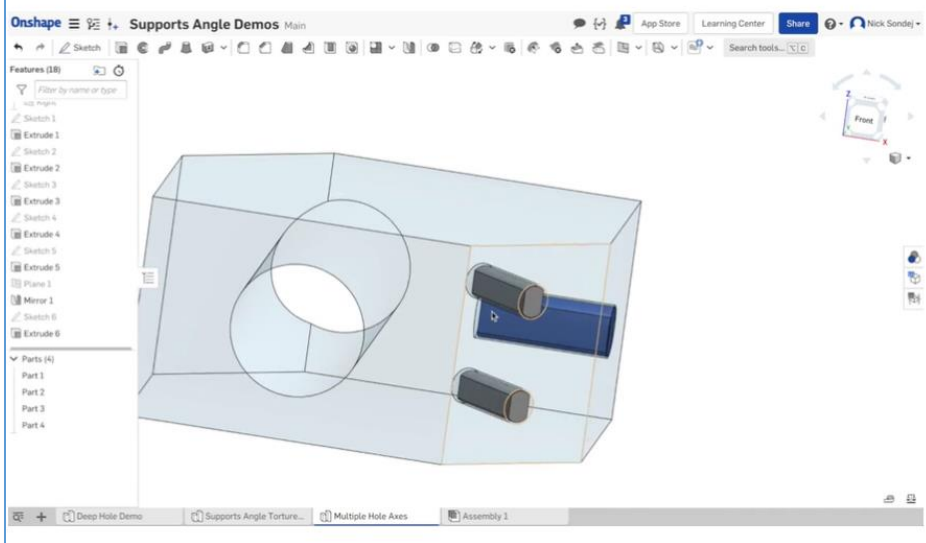
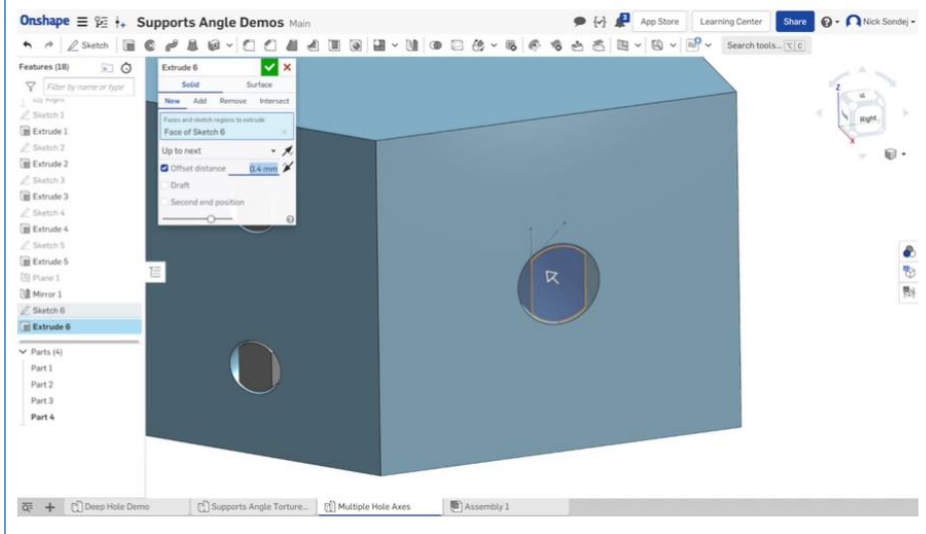
- Notice: Offset distance



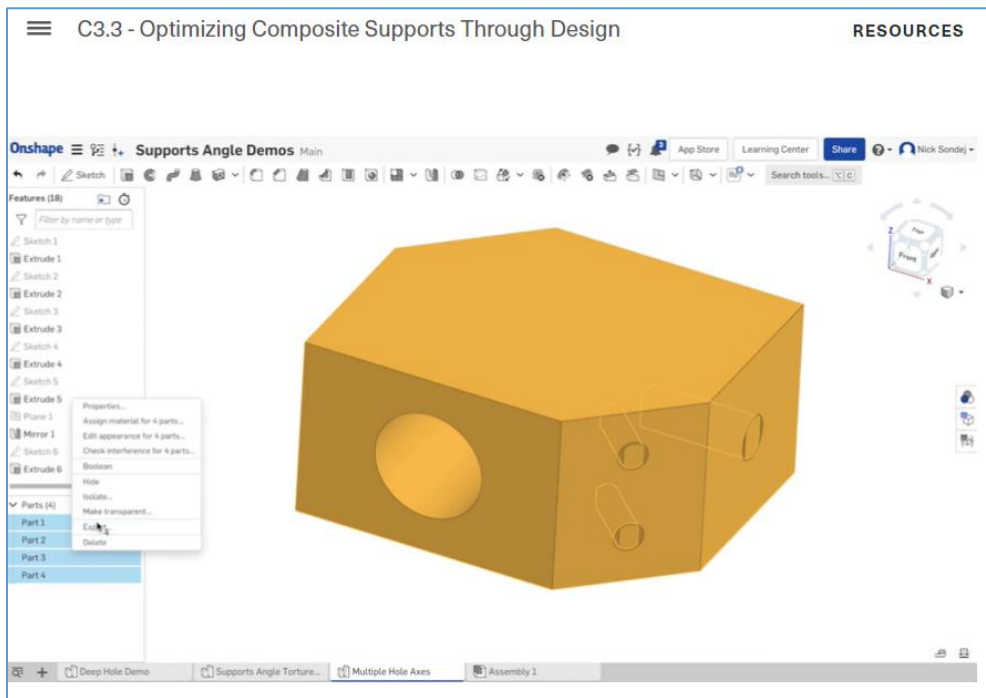
- Mirroring support feature over mid plane.



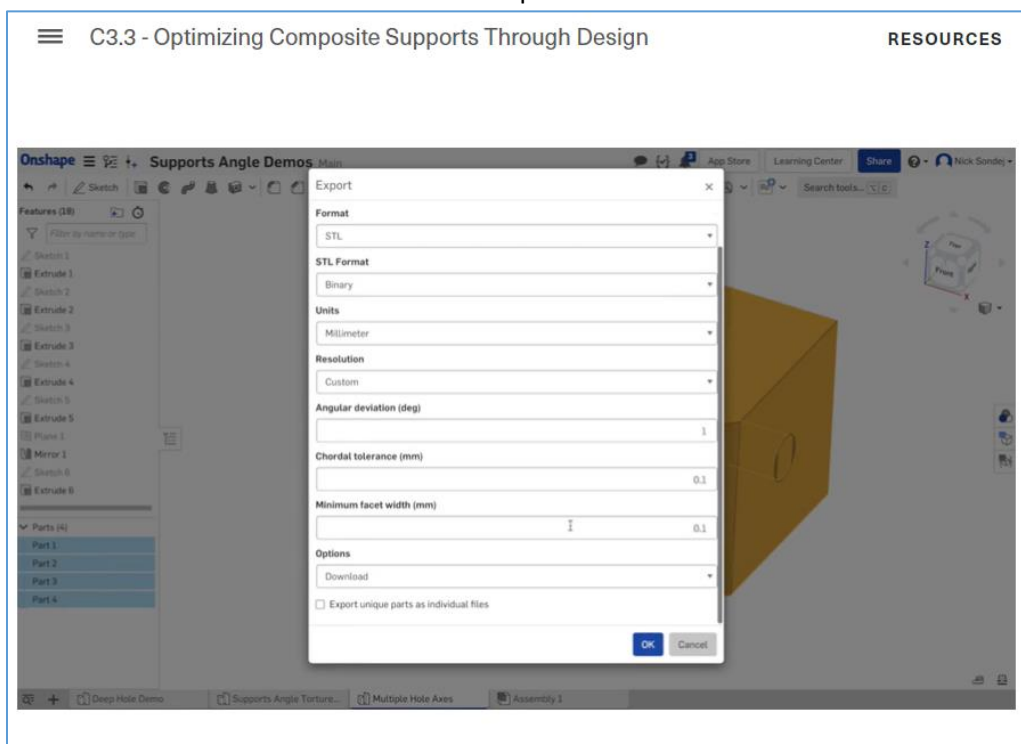




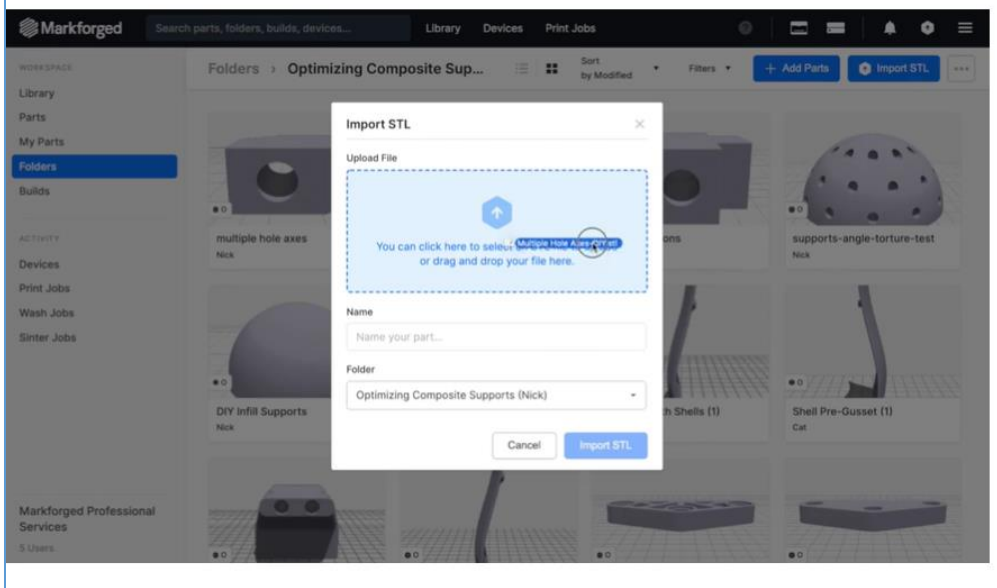
- Support does not touching the part at any point



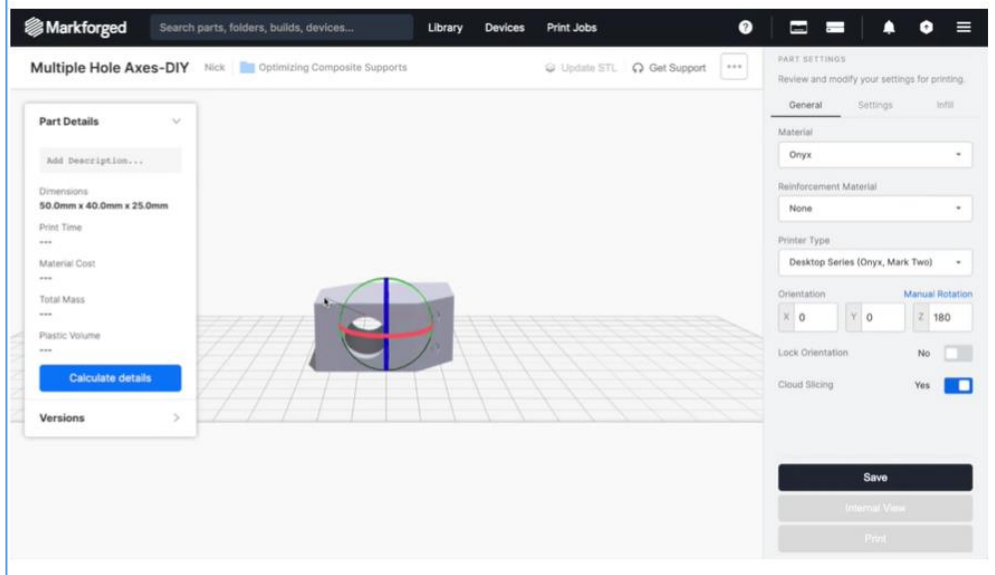
- Select all the bodies and export...

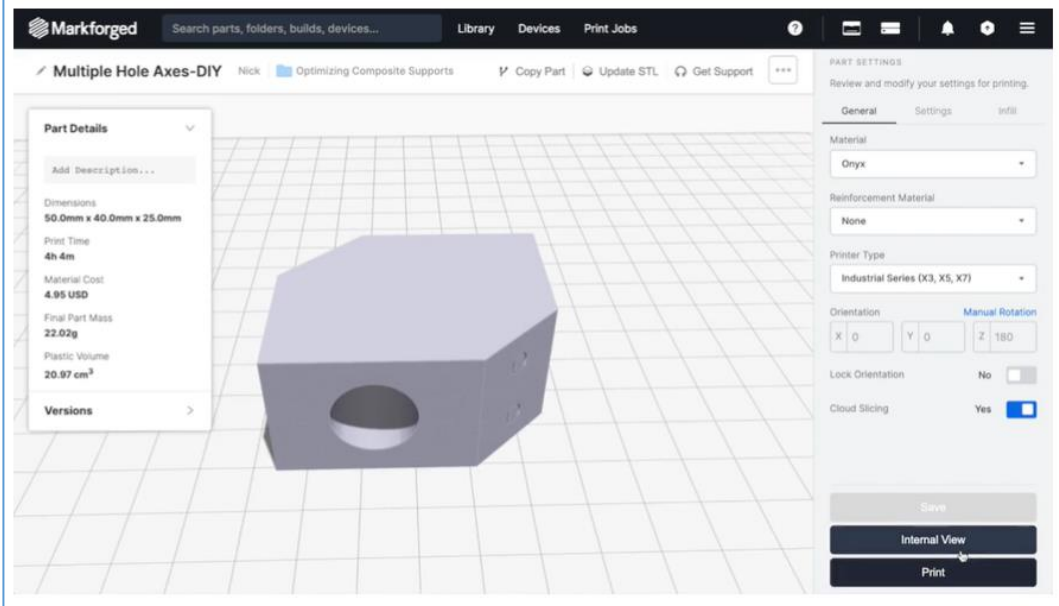
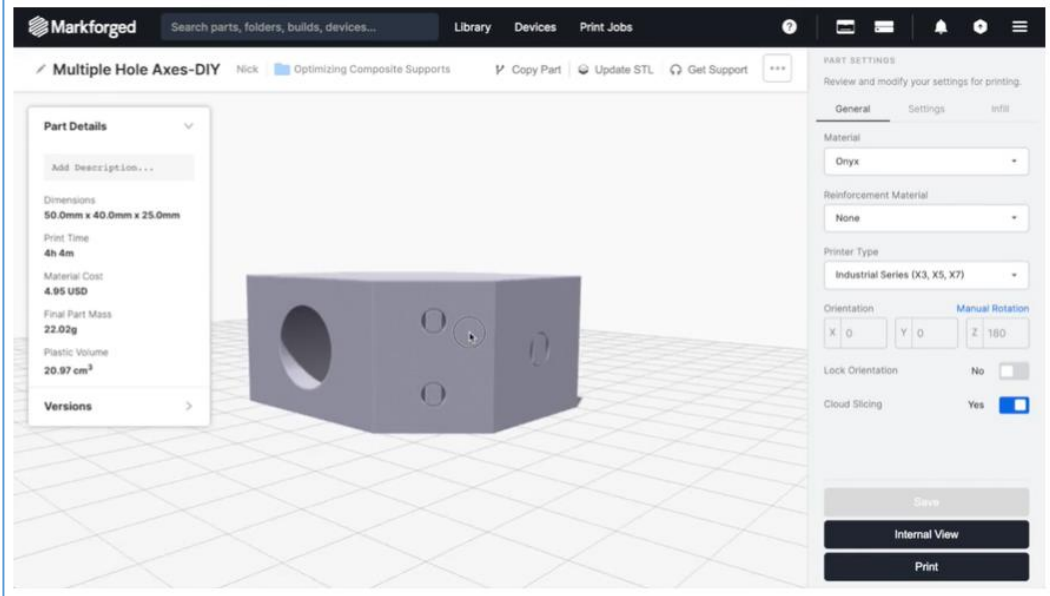


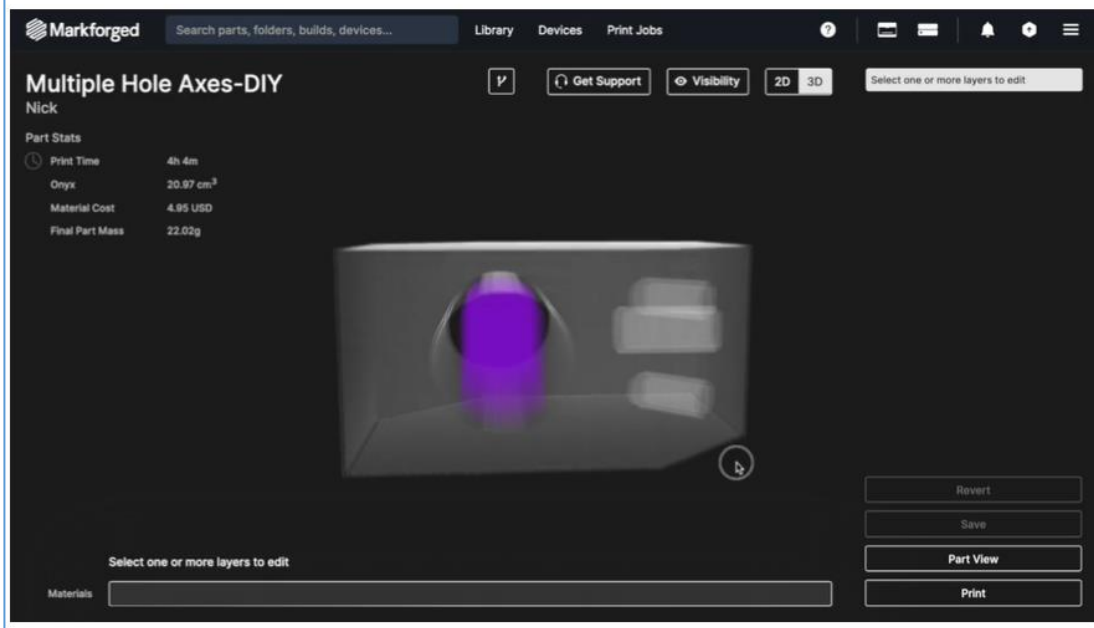
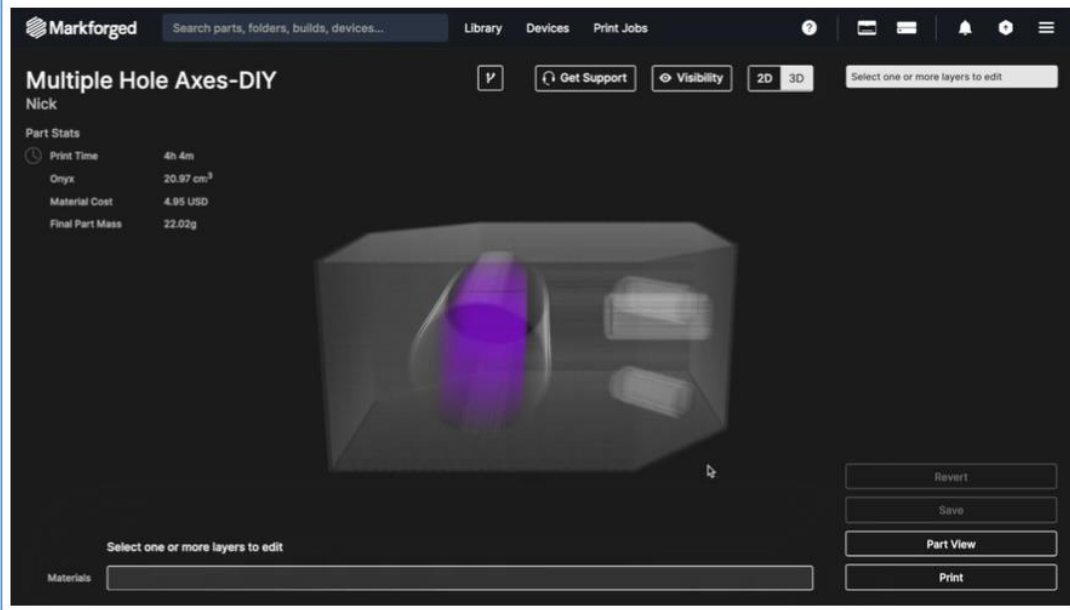
- ..... to a single STL.

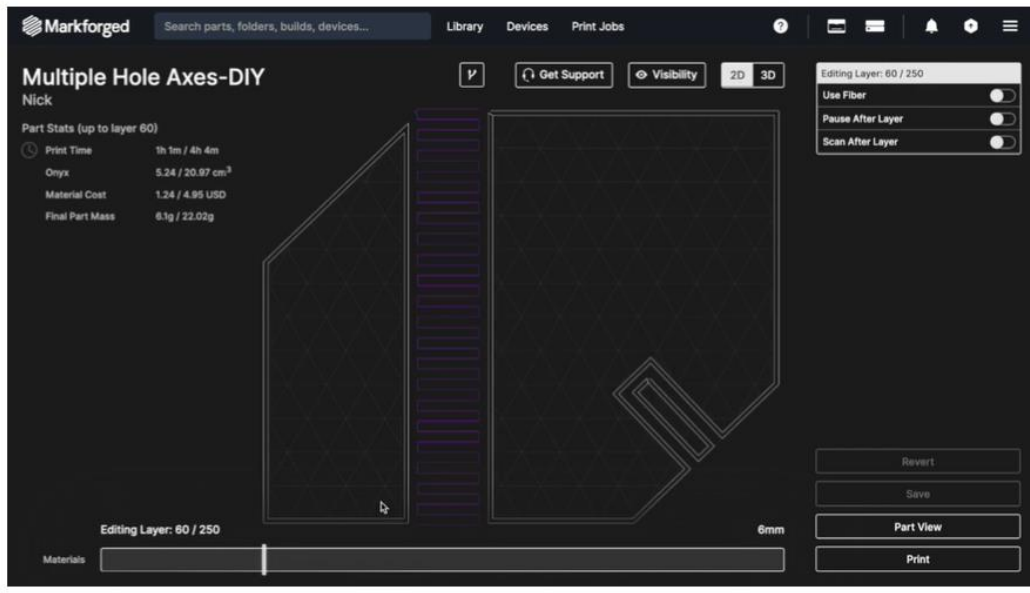
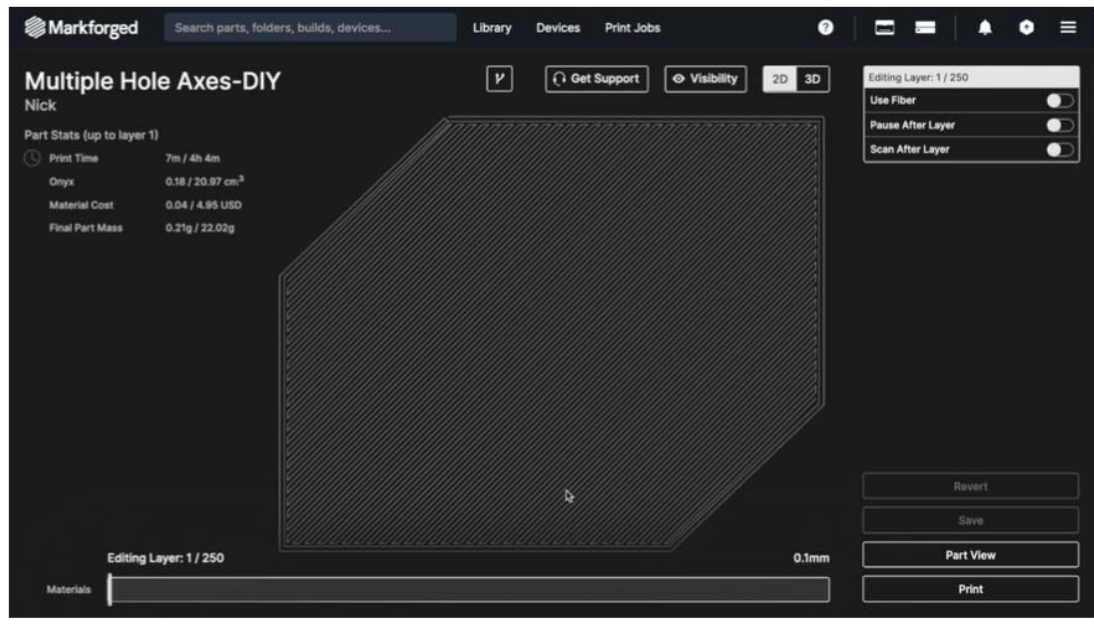


- Import the STL into Eiger.



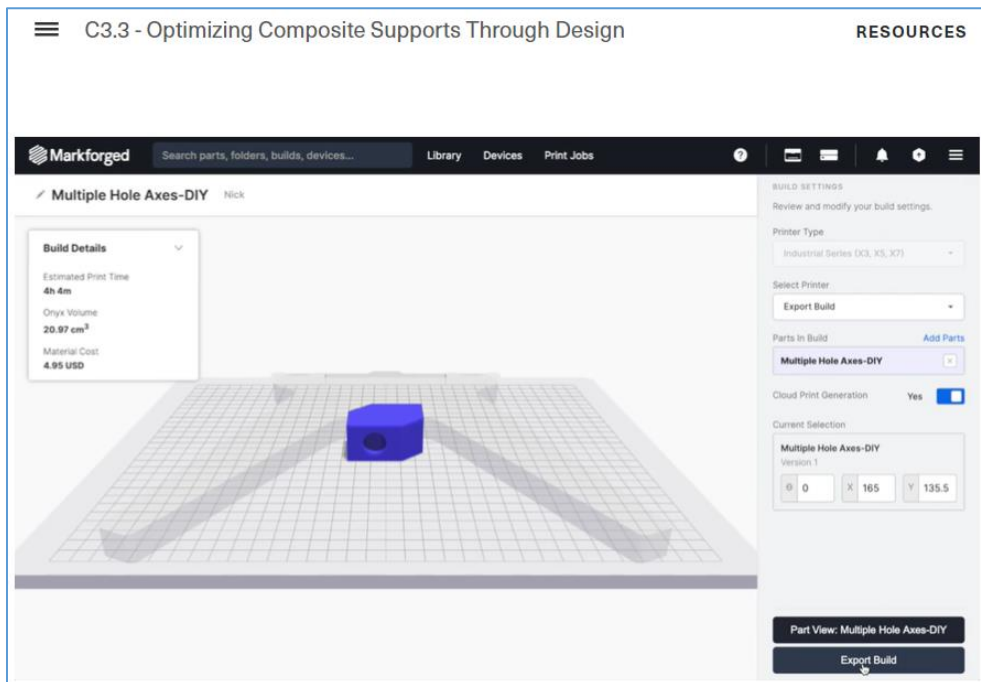






- You could change the support to 90° for a little easier remove of the support material, but it is a pretty large through hole, so you don't have to worry about it.





- And let us print!

Markforged C3.3 - Optimizing Composite Supports Through Design RESOURCES

## DIY Supports Workflow

1. Identify supported areas where you want custom supports
2. Design additional separate bodies in CAD into those areas, with a gap between the part. Suggested starting gap: 0.2 mm in Z-axis, 0.4mm in XY plane
3. Export all bodies as a single STL
4. Import into Eiger and check your work in the Layer Editor
5. Print and enjoy!

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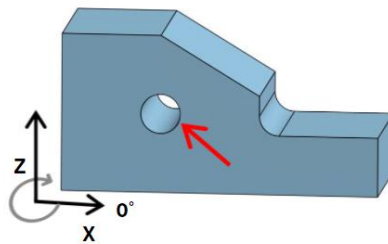
- **DIY Supports Workflow**



- **Module Review**

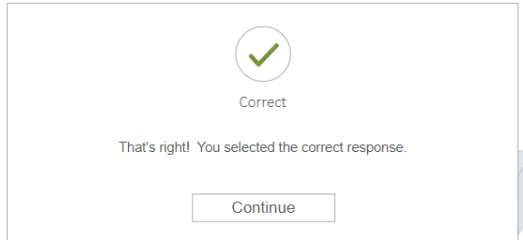
What angle should the Supports Angle feature be set to ensure that supports will be aligned axially (along the length) of the hole in this image?

- 90°
- 0°
- 33°
- 45°



What angle should the Supports Angle feature be set to ensure that supports will be aligned axially (along the length) of the hole in this image?

- 90°
- 0°
- 33°
- 45°



True/False: You should always design your own custom supports in CAD into your 3D printed parts.

- True
- False

True/False: You should always design your own custom supports in CAD into your 3D printed parts.

True

False



Correct

That's right! We're all about efficient solutions here, and you should only spend time designing your own custom supports if you can't optimize the supports in a part with Eiger's existing support tools, which are much faster to use.


Continue

Put the steps in the DIY Supports Workflow in order.

1. Identify supported areas where you want custom supports
2. Print and enjoy!
3. Design bodies in CAD in those areas, with a gap between them and the part
4. Export all bodies as a single STL
5. Import into Eiger and check your work in the Layer Editor

Put the steps in the DIY Supports Workflow in order.

1. Identify supported areas where you want custom supports
2. Design be
3. Export all
4. Import int
5. Print and

  
Correct  
That's right! You selected the correct response.  
[Continue](#)




### Results

Your Score: 100% (30 points)

Passing Score: 80% (24 points)

---

### Result:

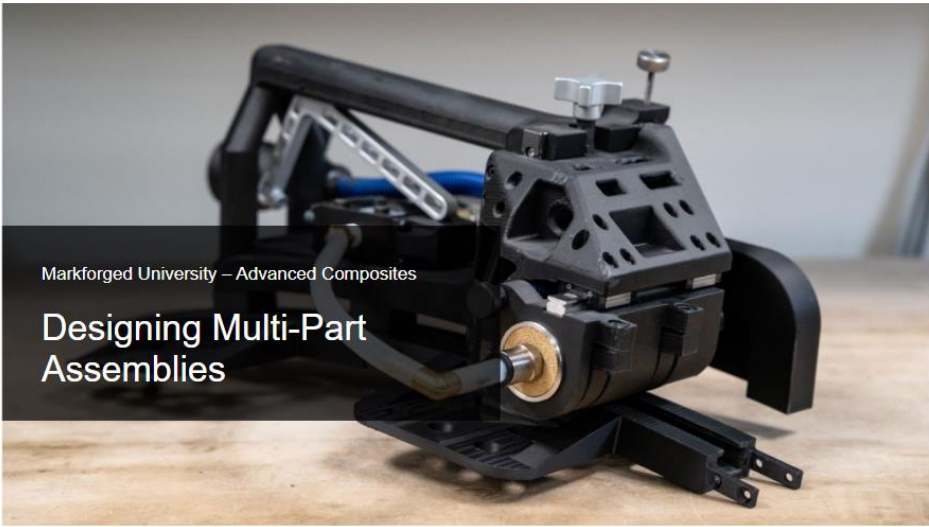
 Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

## C3.4 – Designing Multi Part Assemblies

☰ C3.4 - Designing Multi-Part Assemblies RESOURCES



Markforged University – Advanced Composites

**Designing Multi-Part Assemblies**

- **Designing Multi Part Assemblies**



## Module Overview

Multi-Part Assemblies Through History

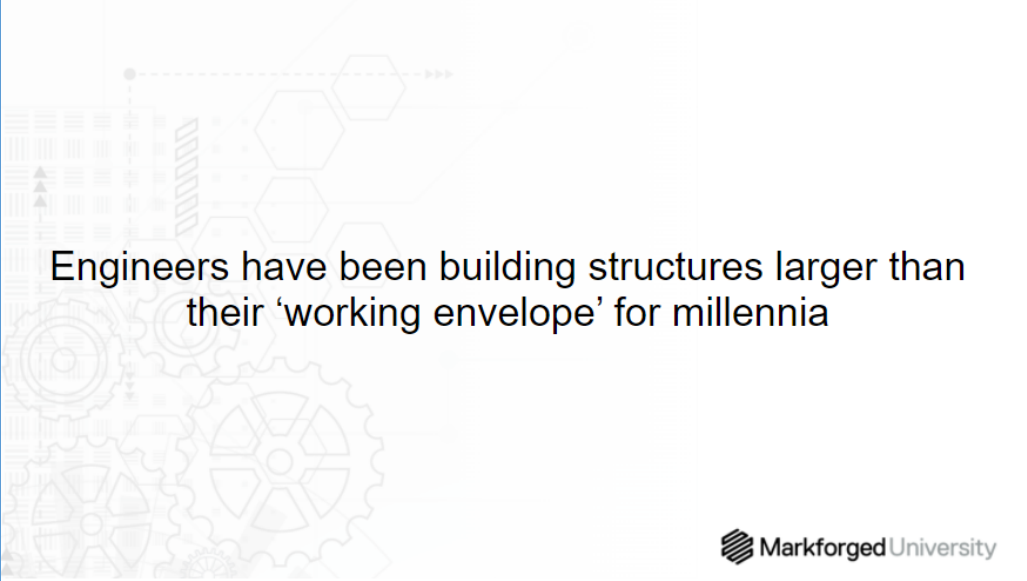
Why Break Up a Part?

How to Do It Workflow

Demo: Creating a Multi-Part Assembly



- **Module Overview**



Engineers have been building structures larger than their 'working envelope' for millennia



- **An Age-old Concept**

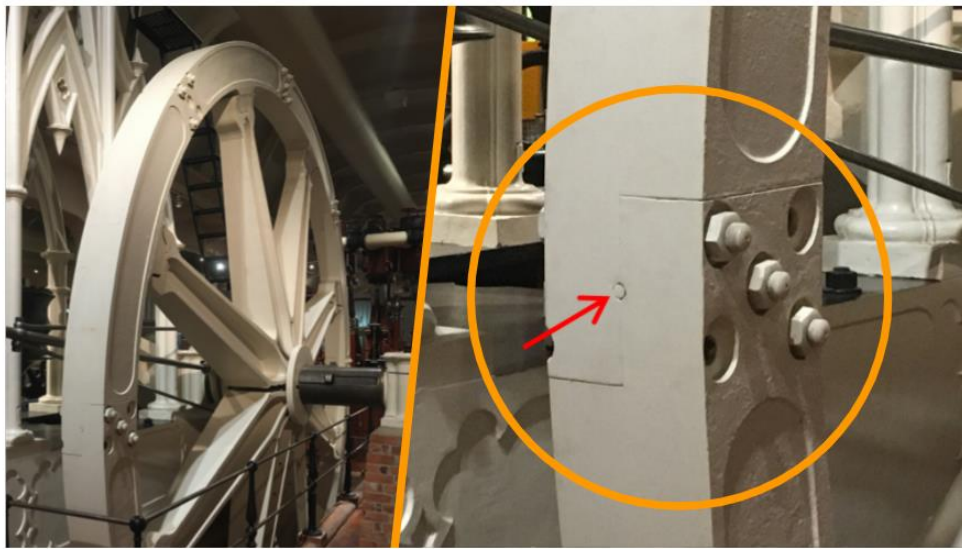
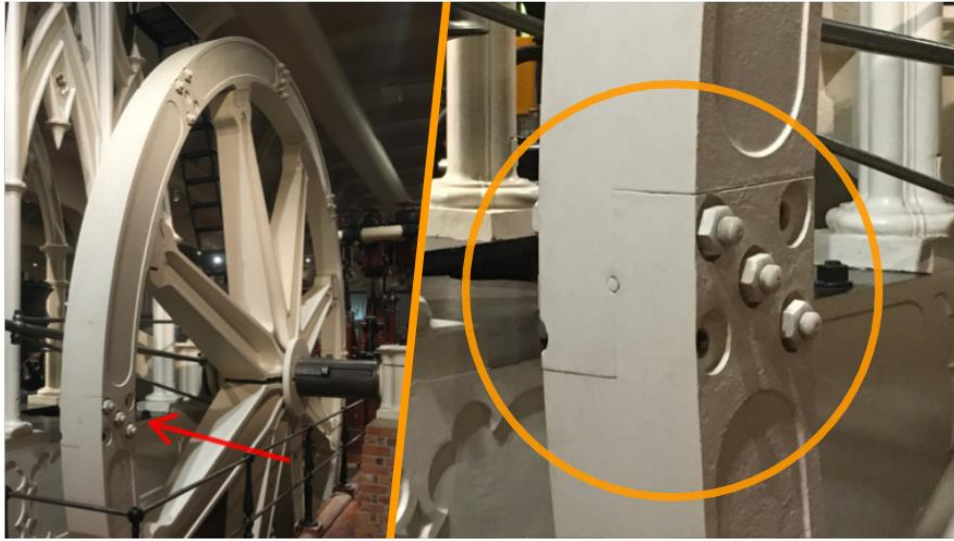
- Example working envelope: A robot (arm) its range of movement.
- Working envelope = The area in which a robot, or any part of one, can move around.



- **Example: Historical Multi-Part Assemblies**
  - The flywheel is probably 4 à 5 meters in diameter



- A assemblies of same cast large segments. Too big to cast as a single piece.
  - To avoid deformations due to cooling down process, or simply too big to handle.



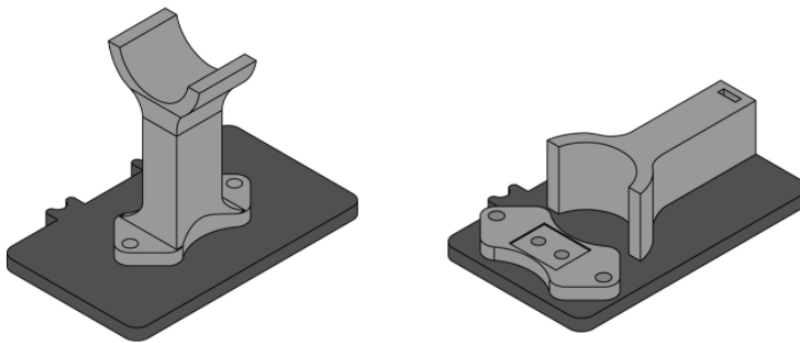
- A dowel pin in the lap joint to help align the pieces.
  - Meant as inspiration from.

Why would we want to break up parts for printing?



- **Why Split Up A Part?**

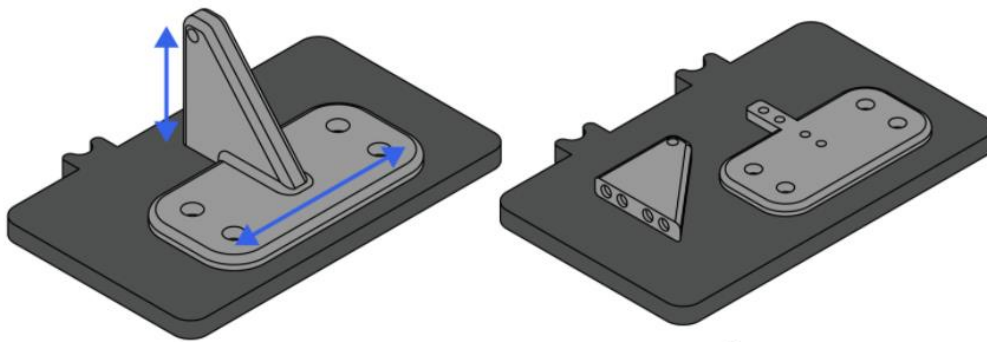
Reduce the risk of breaking along layer lines



- **Z-axis Strength**

- The weakest axis in 3D printed part is the Z-axis, or in between the layers.
- The right alignment is easier to provide fiber.
- The separate parts are bolted together afterwards.
- By doing so the Z-axis weakness is completely eliminated.

## Add continuous fiber to orthogonal planes

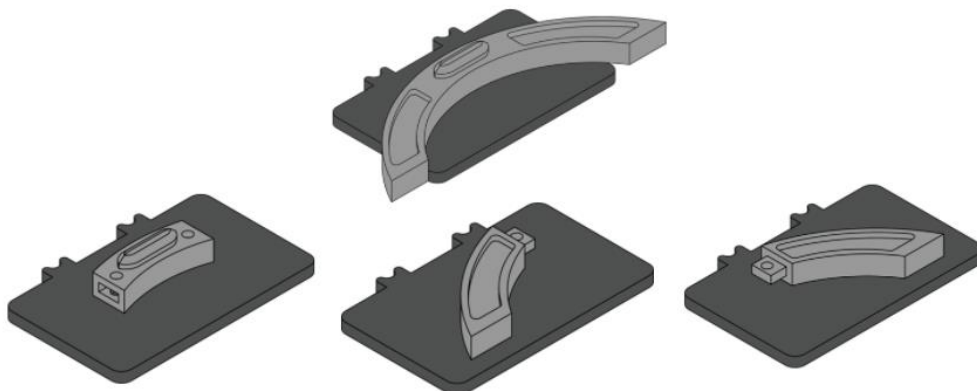


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- **Fiber Layout**

- Multiple non parallel planes we would to reinforce with fiber.
- More easy to provide fiber and avoid Z-axis at the same time.
- Orthogonal = Loodrecht op elkaar stand.
- Assemblies with dowel pins to create strengthen and accurate alignment.

## Print parts that are too big for a single print



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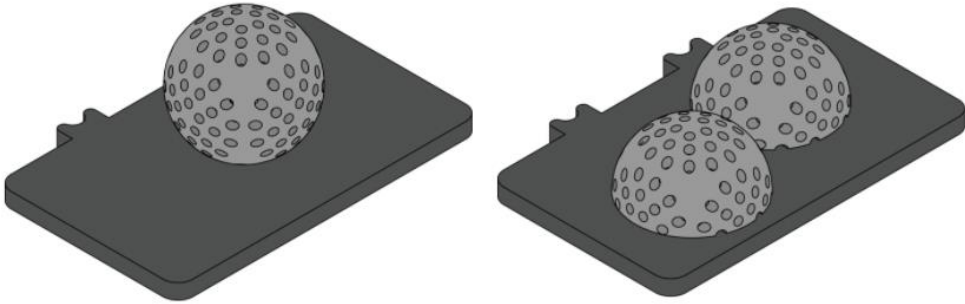
- **Over-sized Parts**




- Choose a affective joint strategy.

☰ C3.4 - Designing Multi-Part Assemblies RESOURCES

### Meet surface finish requirements



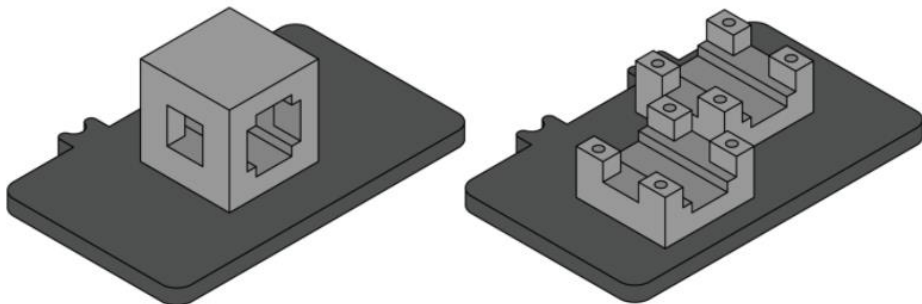



- **Maintaining Surface Finish**

- Meet requirements = voldoen aan eisen.

☰ C3.4 - Designing Multi-Part Assemblies RESOURCES

### Print without supports.

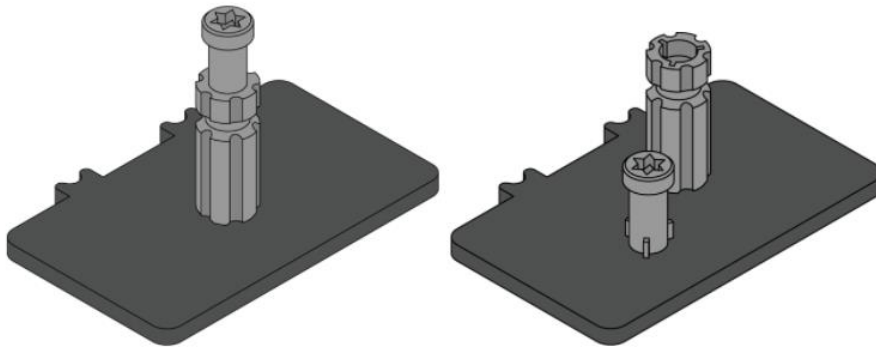




- **Support Reduction**



Separate reusable parts from consumable features.

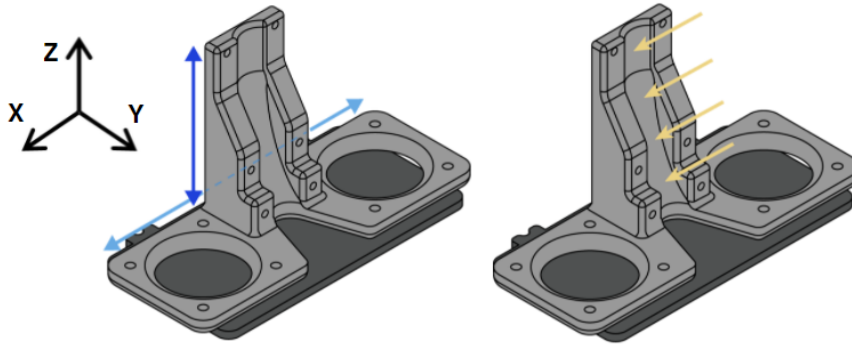


- **Design for Maintenance and Consumability**
  - Consumability = verbruik

What is the process for breaking up parts for printing?

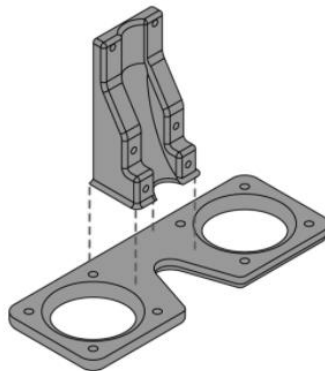
- **Multi-Part Assembly Process**

### Identify functional requirements



- **Identify Functional Requirements**
  - 2 Main planes requires strength: X-Y-plane and Z-Y-plane and are not parallel
  - So split up is needed for upper reason and size.

### Determine the regions to be isolated



- **Determine Where to Split**

Determine the planes used for splitting

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- **Identify Split Planes**

- The bottom section is also too big.

Split the part in CAD

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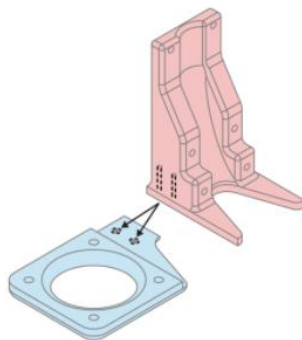
- **Split the Part into Pieces**

### Split the part in CAD



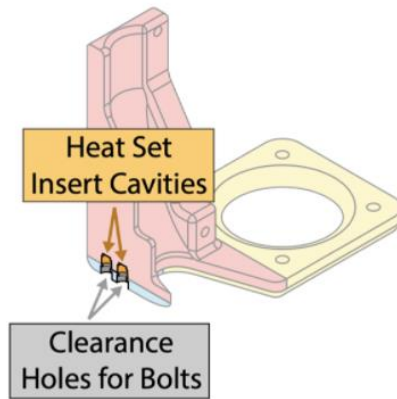
- 3 Pieces with lap joint.
- Oriented in a way to be best reinforced with composite fiber, in the way the best meet the functional requirements.
- First we have to make sure that the right way to join the parts back together is chosen.

### Evaluate options for joining bodies after printing



- Evaluate Joint Options

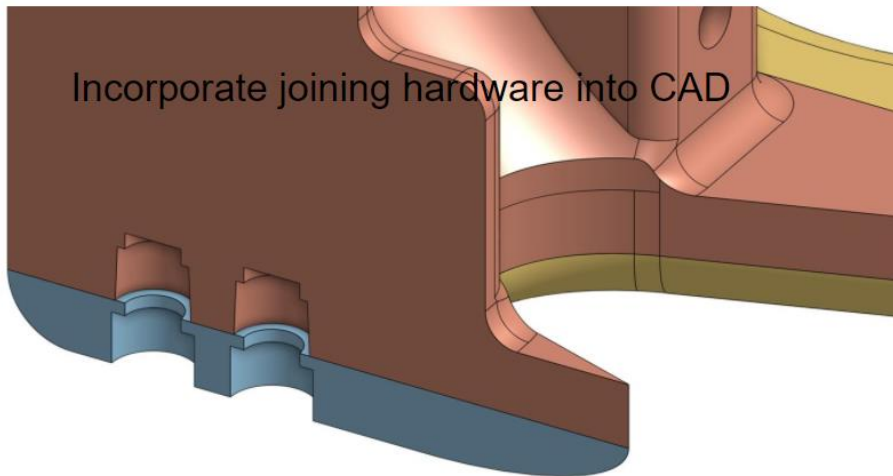
## Incorporate joining hardware into CAD



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- **Adjust CAD for Hardware**

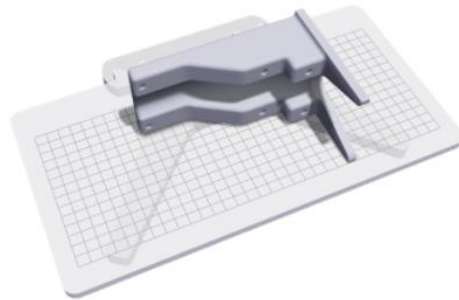
## Incorporate joining hardware into CAD



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- Taper Holes at the bottom of the upper part for heat inserts to be installed after printing.

Export bodies as separate STL files and import into Eiger for printing

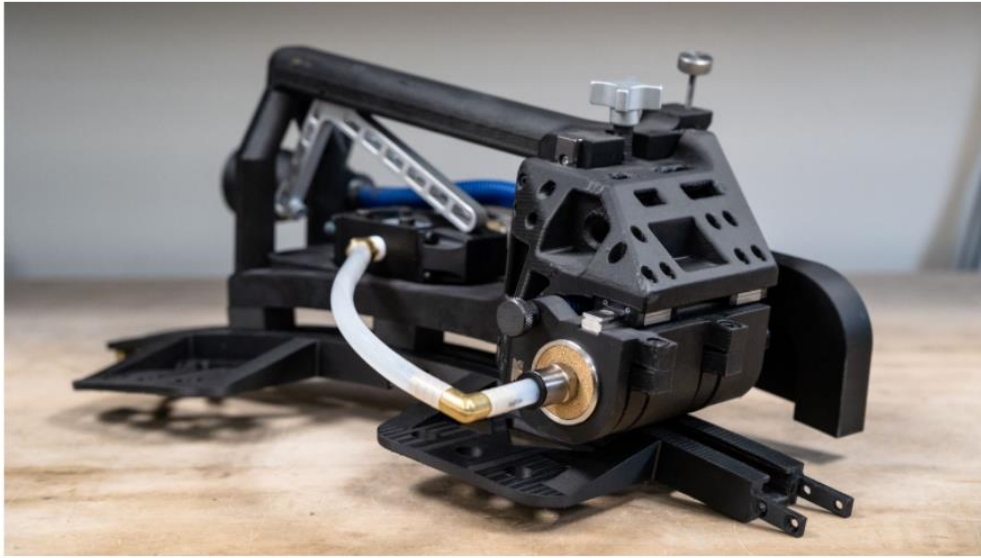


- **Eiger Configuration**

Multi-Part Assemblies in the Real World

- **Multi-Part Assemblies in the Real World**

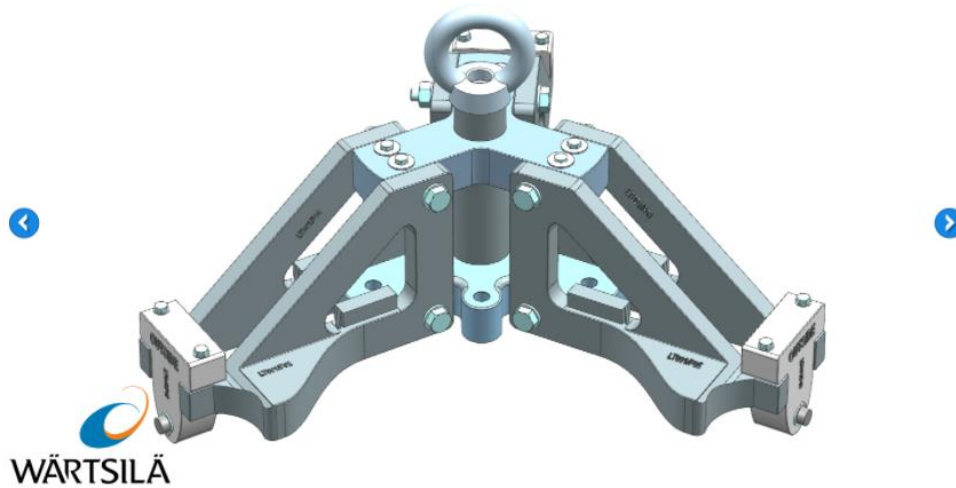




- **Example: Siemens Saw Housing**



- **Example: Wärtsilä Lifting Tool**
  - Used for lifting 240kg engine pistons.
  - Tooling like this are extremely heavy requires 2 persons.



- The tool is able to lift 160kg as needed to and it actually the first 3D-printed CE-certified lifting tool in the world.



- **Example: Lean Machine Vise**
  - Vise = Bankschroef / machineklem

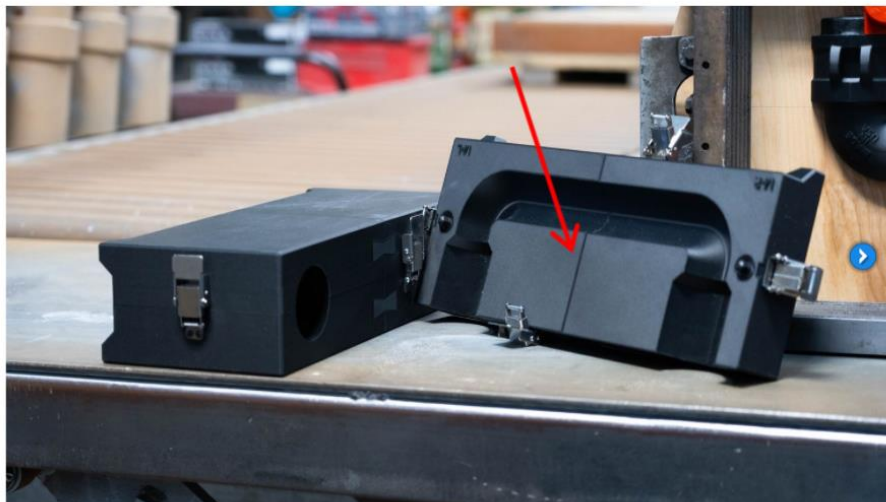


- Build end of a bed on long travel CNC-mills.
- It is much lighter and is therefore much lighter weight on the bed.
  - To avoid conditional wear during operating of the machine at the end of the bed.

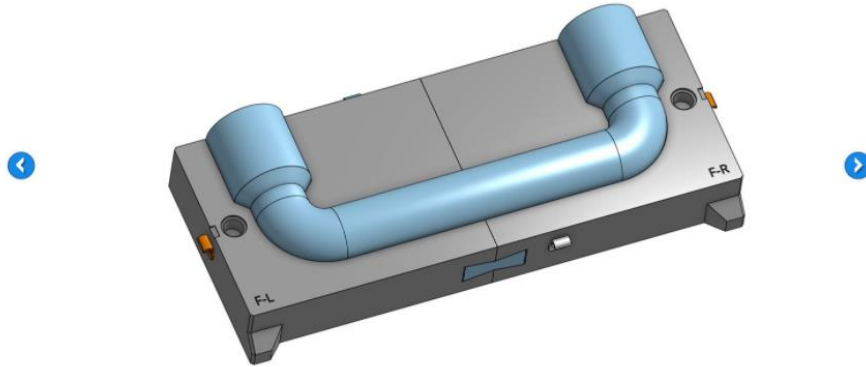




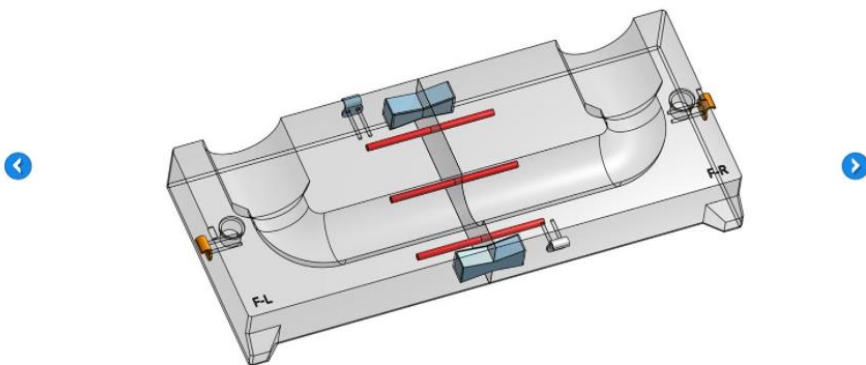
- **Example: Sand Casting Core Box**

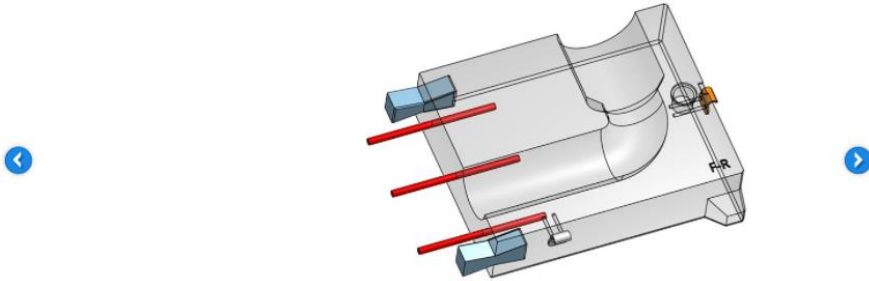


- Split up and joint together as an assembly

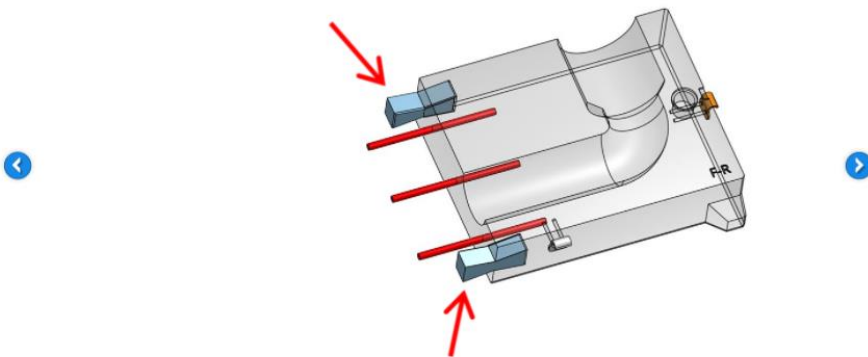


- CAD of the core box.



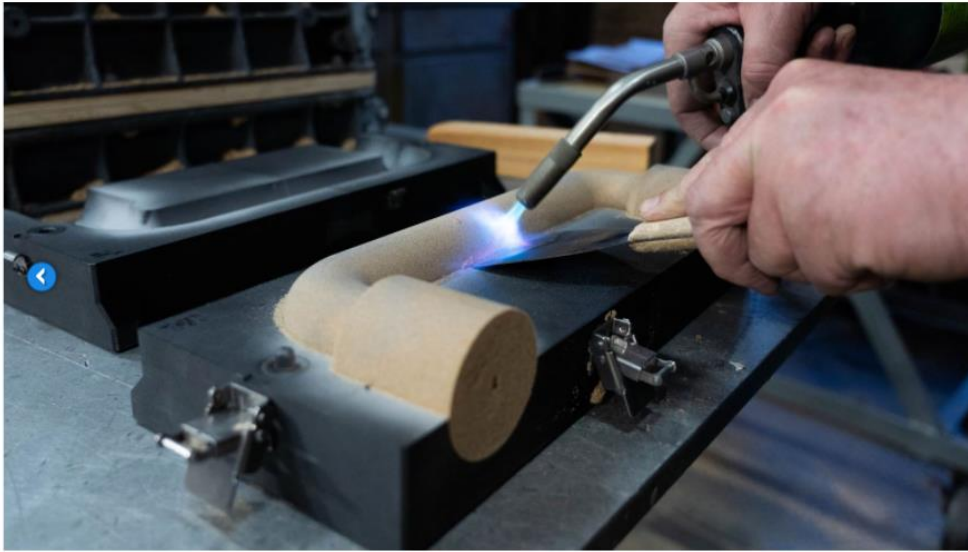


○ Dowell pins



○ Duck tailed inserts





- **Module Review**


Which of the following is NOT a reason to split a part into smaller pieces and re-design it as an assembly of 3D printed parts?

- It's required to be able to machine parts after printing
- To add strength in multiple non-parallel planes
- Part is too large to fit on print bed
- Surface finish considerations



Which of the following is NOT a reason to split a part into smaller pieces and re-design it as an assembly of 3D printed parts?

- It's required to be able to machine parts after printing
- To add strength in multiple non-parallel planes
- Part is too large to fit on print bed
- Surface finish considerations



Correct

That's right! You selected the correct response.

[Continue](#)




Put the following steps for designing a multi-part assembly in order:

1. Split the part in CAD
2. Identify your functional requirements
3. Add design features for any hardware required to re-join the parts
4. Determine where the part needs to be split
5. Export each part individually as an STL and configure them in Eiger

Put the following steps for designing a multi-part assembly in order:

1. Identify your functional requirements
2. Determine where the part needs to be split
3. Split the part in CAD
4. Add design features for any hardware required to re-join the parts
5. Export each part individually as an STL and configure them in Eiger



Correct

That's right! You selected the correct response.

Continue


True/False: The design strategy of building an assembly from a collection of parts is a brand-new process that has no historical design precedent.

- True
- False



True/False: The design strategy of building an assembly from a collection of parts is a brand-new process that has no historical design precedent.

- True
- False



Correct

That's right! You selected the correct response.

[Continue](#)




☰ C3.4 - Designing Multi-Part Assemblies RESOURCES

Results

Your Score:	100% (30 points)
Passing Score:	80% (24 points)

---

Result:


 Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

### C3.5 – Post-Processing Composite Parts

☰ C3.5 - Post-Processing Composite Parts RESOURCES



Markforged AM University – Advanced Composites

## Post-Processing Composite Parts

- **Post-Processing Composite Parts**

## Module Overview

Post-processing and Print Configuration

Adhesives & Coatings

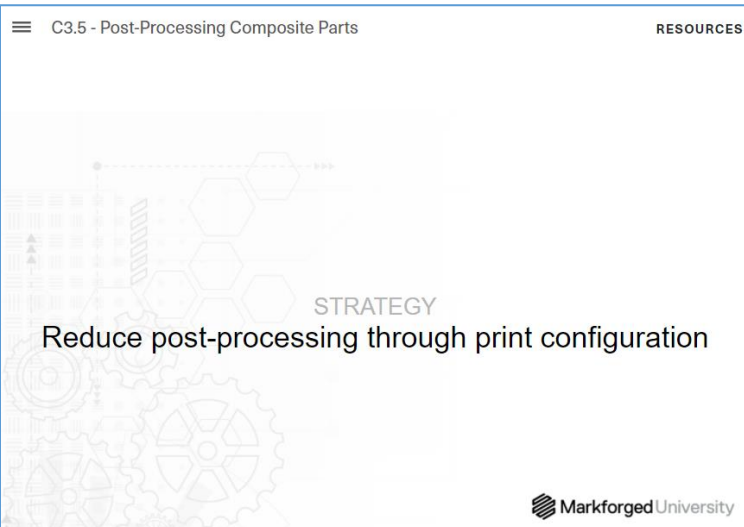
Machining Composite Parts

Marking and Labeling



- **Module Overview**

- Configureren is het samenstellen van een product uit verschillende basisbouwstenen, de keuze en schikking van componenten die samen een systeem met de gewenste functionaliteit moeten vormen.



- **Reduce post-processing through print configuration**



☰ C3.5 - Post-Processing Composite Parts RESOURCES

Layer height impacts surface finish and print time

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- **Layer height impacts surface finish and print time**

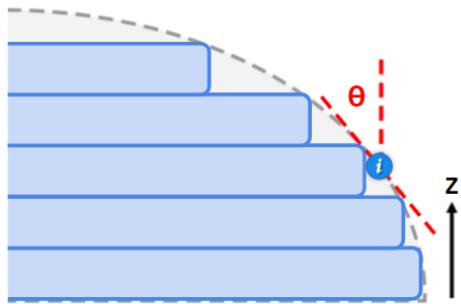
☰ C3.5 - Post-Processing Composite Parts RESOURCES

Review: Parts are built one layer at a time

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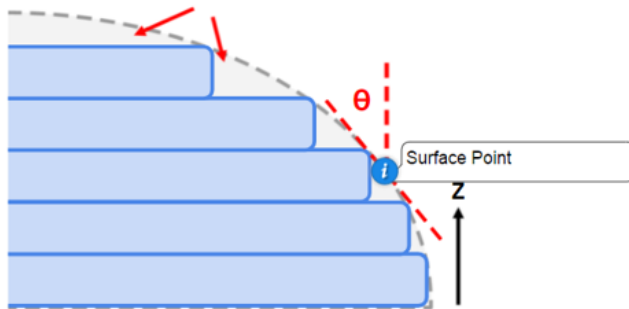
- **Review: Parts are built one layer at a time**

Surface Finish → Tangent Angle + Layer Height

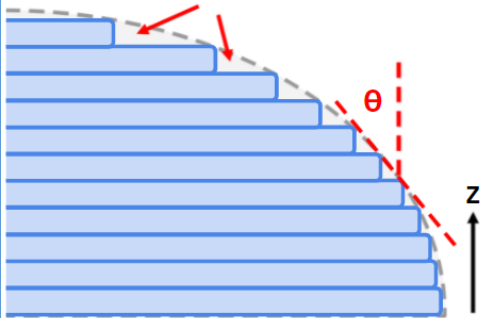


- Service Finish at Thicker Layer Heights

Surface Finish → Tangent Angle + Layer Height



### Surface Finish → Tangent Angle + Layer Height

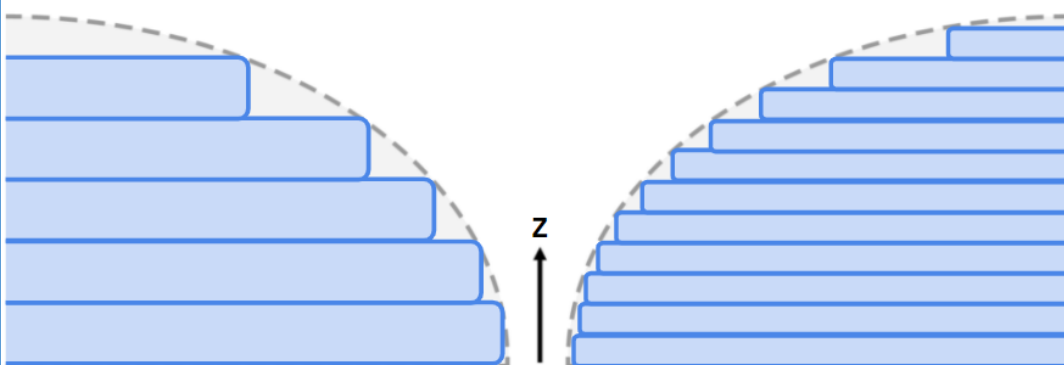


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- **Service Finish at Thinner Layer Heights**

- Is for plastic only. CFF composite fibre needs set layer height. So reinforce the part the layer height depends of the chosen fibre. 0.1mm Layer height for continues Kevlar and fibre glasses and 0.125mm for continues carbon fibre.

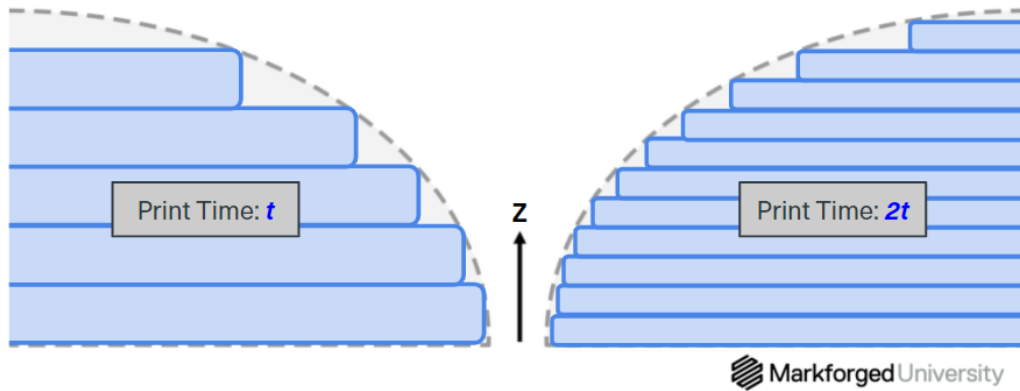
### Finer Layers → Better Resolution



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- **Finer Layers → Better Resolution**

## Coarser Layers → Faster Printing



- **Coarser Layers → Faster Printing**

- Coarser = Grover.

## Turbo Infill – An Experimental Bit of Both Worlds



- **Needed Faster? Try Turbo Infill**

THEME

Choose print configuration settings to minimize post-processing, then print time



- **Theme: Minimizing Post-Processing**



- **Adhesives**
  - Lijmen.

## Onyx-Onyx Bonding



High bond strength with LOCTITE®:

- **LOCTITE 401** - for a strong, rigid bond
- **LOCTITE 4861** - when you need a strong but flexible bond



- **Onyx-Onyx Bonding**

## Onyx-Other Materials Bonding

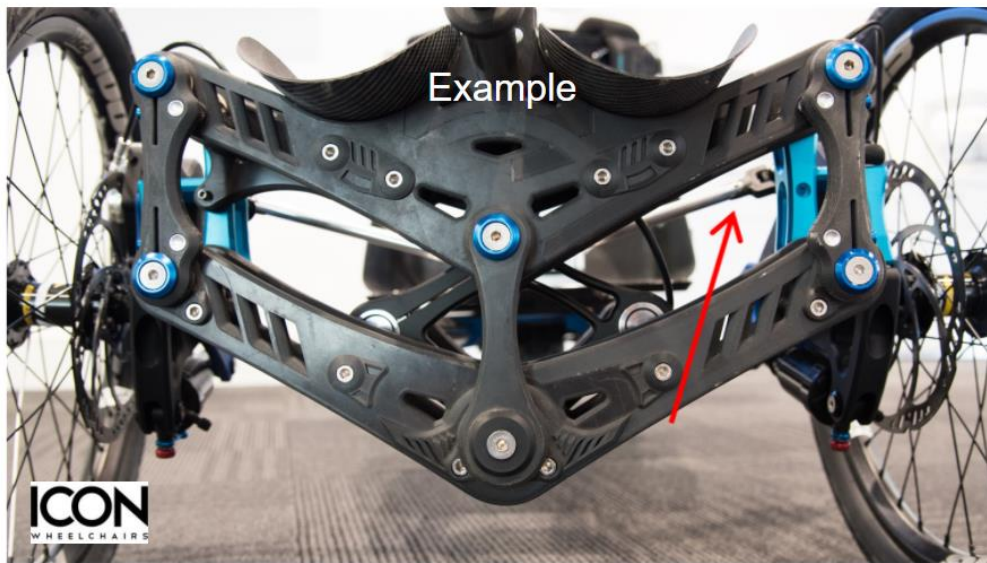
Epoxies are excellent:

- **3M Scotch-Weld DPxxx series**
  - E.g. **DP100**, DP110, DP420
  - Choose epoxy based on functional requirements
- **Plexus MA380**
  - Proven Onyx-plastics bonding



- **Onyx-Other Materials Bonding**





- **Example**
  - Control arms responsible for the rotation, like a car system.



- **Coatings**

## Spray Paint



Most spray paints adhere well, coat evenly

**NOT** for smoothing rough surfaces (use high build primer)

**Krylon** - good adhesion, brilliant color, lots of options for exotic finishes



- **Spray Paint**

## Filling in Rough Surfaces

Onyx is a nylon 6-based plastic and highly abrasion resistant (hard to sand)

**Best practice:** build up layers of primer and sand smooth between coats

**Downside:** Labor-intensive, slow, loss of dimensional accuracy



- **Filling in Rough Surfaces**

## Water-resist/Vacuum Sealing

Acrylic varnish can:

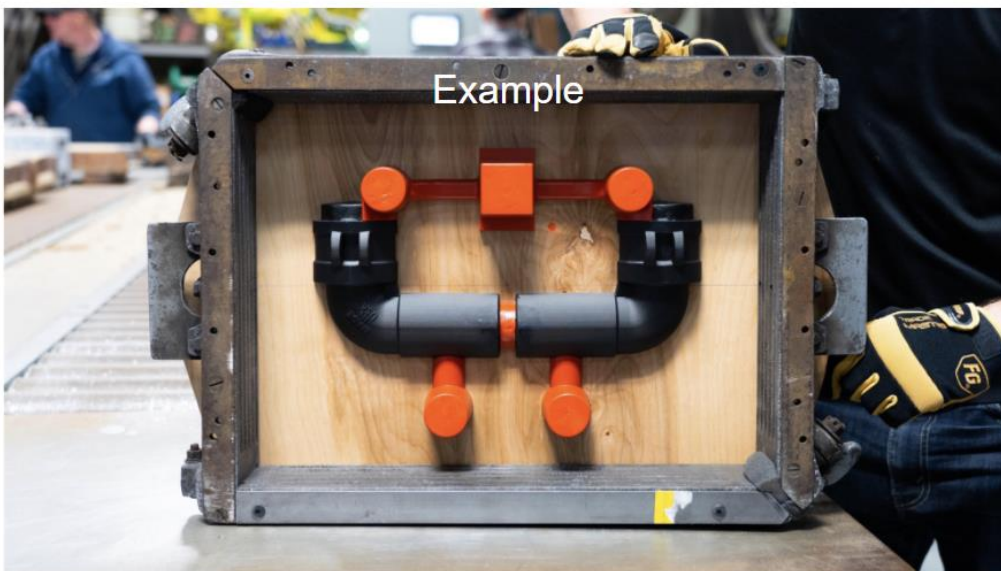
- Add water resistance
- Seal internal channels against leaks

**Liquitex Spray Varnish** (high gloss or matte) is a proven option – available in spray or liquid



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- **Water-resist/Vacuum Sealing**



- **Example**
  - To improve the surface finish and also for easier removing from sand mold, without damaging.



## Machining Composite Parts



- **Machining Composite Parts**

## Machining Tolerances/Walls + Infill

Consider structure of 3DP part

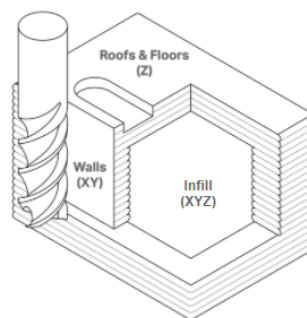
Machining too deep can expose infill

At default settings:

**0.8mm** thick Wall (XY)

**0.4mm-0.8mm** thick Roofs/Floors (Z)

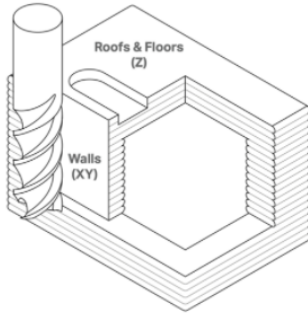
**Tip: Increase Walls or Roofs/Floors**



- **Machining Tolerance/Walls + Infill**

- Expose = blootleggen

## Machining Recommendations

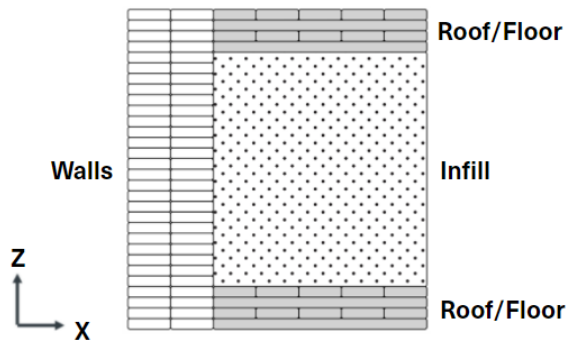


Wall Layers:	4
Roof/Floors:	10
XY Cut Depth:	0.2 mm/0.6 mm [0.008 in/0.024 in]
Z Cut Depth:	1.5x/2.5x Layer Height 0.15 mm/0.25 mm [0.006 in/0.01 in]

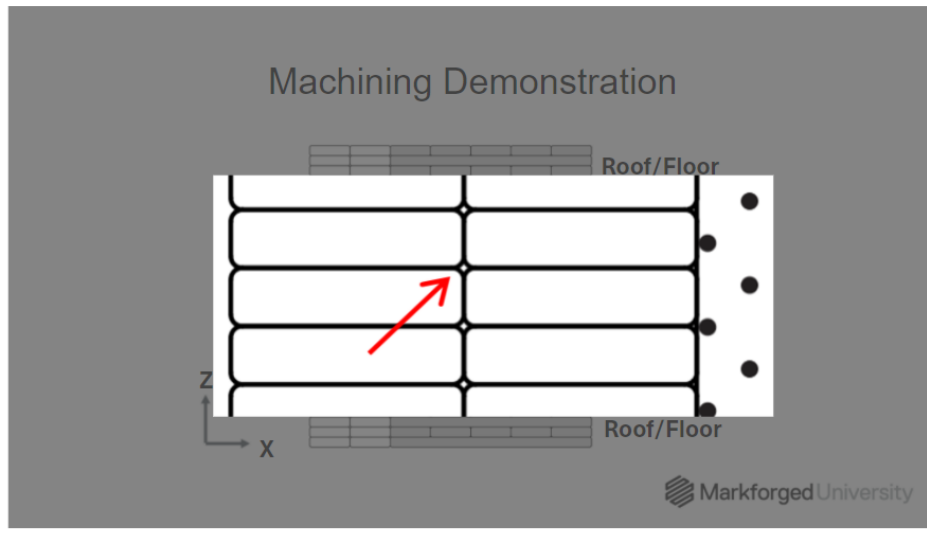


- **Machining Recommendations**

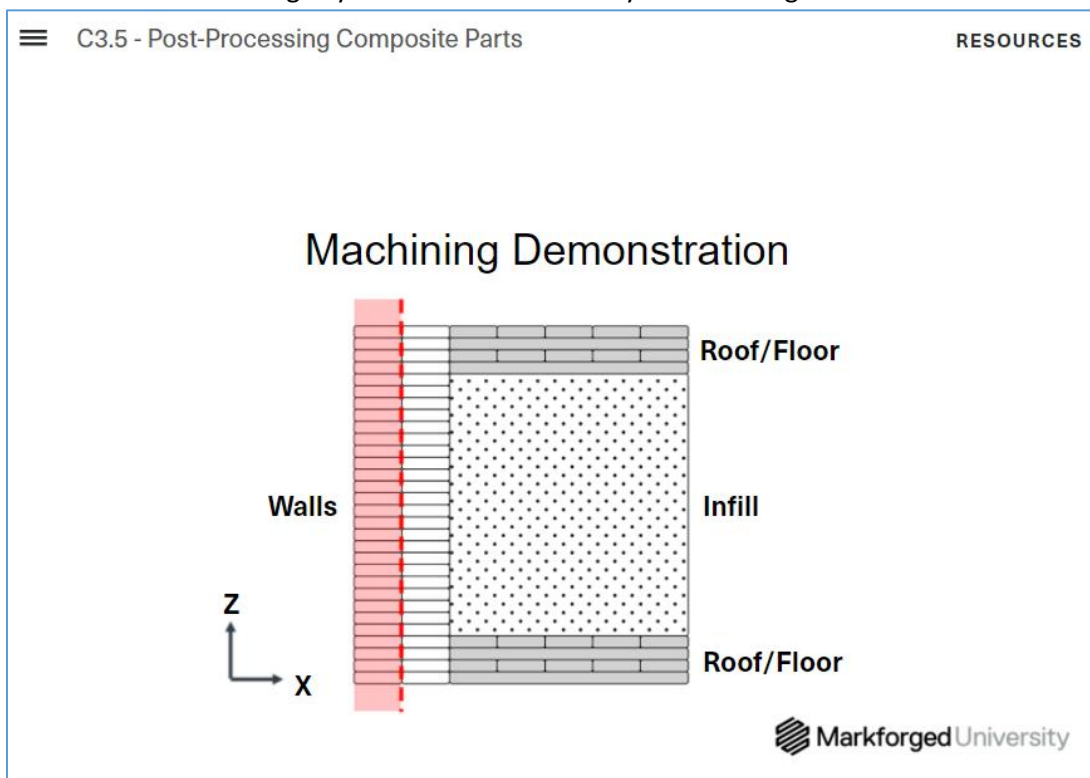
## Machining Demonstration



- **Machining Activity**



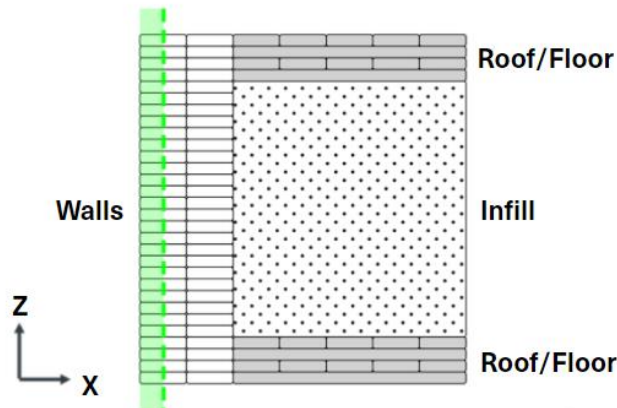
- Zooming in you can see a risk when you machining at this location.



- This toolpath is not what we want.



### Machining Demonstration



- We want the cutting toolpath in the middle of the wall.

### Examples



- Examples





- **Marking and Labeling**



- **Metallic Sharpie (trademark) and Engrave**



## Fiber Laser Marking



High contrast, high precision marking

Enables high resolution labeling

Rapid marking technique

**Tip: Must be fiber laser, not CO<sub>2</sub>**

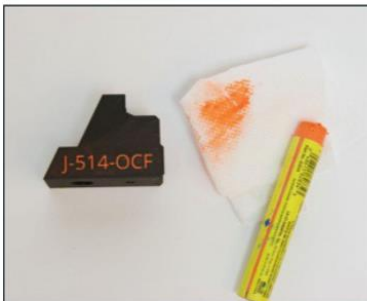
**Con: More expensive equipment**



- **Fiber Laser Marking**



## Labeling with Engraving Filler



Fluorescent wax/lacquer filler

High contrast in engraved labels

**Sources:**

[Engraving Filler - Amazon](#)

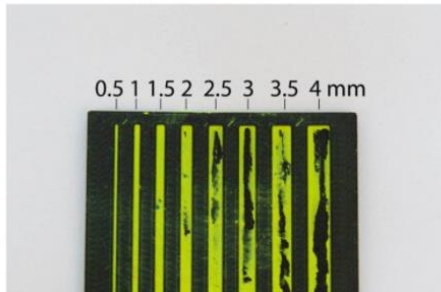
[Fluorescent Paint Markers](#)



- **Labeling with Engraving Filler**

- [https://www.amazon.com/s?k=engraving+filler&ref=nb\\_sb\\_noss\\_1](https://www.amazon.com/s?k=engraving+filler&ref=nb_sb_noss_1)
- [F Markal Paint Markers - Buy F Markal Paint Markers Online \(markingpendepot.com\)](#)

## Engraved Labeling Specs



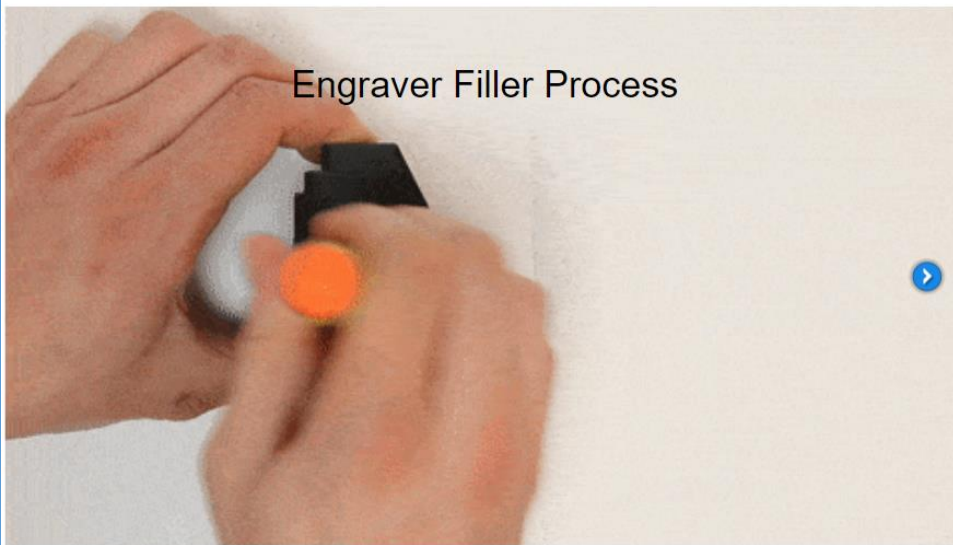
0.5 mm – 1 mm ideal path width

0.5 mm – 1 mm engrave depth

Horizontal location to avoid supports



- **Engraved Labeling Specs**








- **Module Review**

Mark all of the things you need to consider when machining an Onyx part with default wall, roof and floor, and triangular plastic infill settings.

- Wall thickness
- Roof and floor layers
- Plastic infill type
- Markforged printer model

Mark all of the things you need to consider when machining an Onyx part with default wall, roof and floor, and triangular plastic infill settings.

- Wall thickness
- Roof and floor
- Plastic infill
- Markforged



Correct

That's right! You'll want to consider whether your part has a hollow infill and if it does how thick the walls and roof and floor layers are, to avoid breaking into the hollow infill of the part.




True/False: Configuring a part to print with a thinner layer height will reduce the print time, since the thinner layers cool faster.

- True
- False



True/False: Configuring a part to print with a thinner layer height will reduce the print time, since the thinner layers cool faster.

- True
- False



Correct

Correct! Printing a part with a thinner layer height will increase the print time since there are more layers to print. The thinner layer height will produce a smoother, higher resolution surface finish however.

[Continue](#)


What is an effective technique to add high contrast labeling to a 3D printed part

- Fiber laser marking
- Running a metallic marker across engraved text
- Creating engraved text with a high contrast filler
- All of the above



What is an effective technique to add high contrast labeling to a 3D printed part

- Fiber laser marking
- Running a
- Creating e
- All of the a



Correct

That's right! All of these can be effective techniques for adding highly visible labeling to a 3D printed part.




True/False: The effects of a thinner layer height are most noticeable on areas of a part whose surface tangent angles are large (close to but less than 90° from the vertical)

- True
- False



True/False: The effects of a thinner layer height are most noticeable on areas of a part whose surface tangent angles are large (close to but less than 90° from the vertical)

- True
- False



Correct

That's right! Finer layer heights are more important when you need a high surface finish on areas of a part that are nearly (but not perfectly) horizontal, or parallel to the print bed. Printing these features with a layer-by-layer additive process results in the largest deviation from the as-designed geometry. Thin layer heights have much less effect on the surface finish of features with vertical or near-vertical walls and perfectly horizontal tops and bottoms.

Continue



### Results

Your Score: 100% (40 points)  
Passing Score: 80% (32 points)

### Result:

 Congratulations, you passed.

[Finish Module](#)

[Review Quiz](#)

## Software Updated on 2022-11-08



This release is focuses on improving new materials and expanding printer compatibility.

### Industrial Printers:

**Smooth TPU is now available on the [web shop](#)!** Users can now print this high quality, flexible material on X3 (Gen 2), X5 (Gen 2), and X7 (Gen 2) printers or any industrial with an [A3648 extruder](#) installed. Make sure to read through the [Getting Started with Smooth TPU guide](#) before loading. Happy printing!

- S-TPU release for X3, X5, and X7 printers with an [A3648 extruder](#).

### Onyx Pro (Gen 2), Mark Two (Gen 2), Industrials:

- Improve P-PLA print reliability and reduce frequency of extrusion issues.
- Reduced time required for S-TPU pull routine.

### FX20:

Close

## Afgelopen CGI



Rense Veenstra (student)

Aan: Henk Spaan; Harrie Goes



Do 20-7-2023 12:59

Goedendag Henk,  
Goedendag Harry,

N.a.v. de afgelopen CGI wil ik nog even reageren.

Ik laat het op het moment suprême misschien niet zo merken, maar het heeft me wel degelijk diep geraakt en dat ijde nog (en nog). Ik erken de uitglijders die ik heb gemaakt en bedankt jullie voor de duidelijke feedback.

Ik moet zeggen dat het nog niet eens bewuste poging was om de boel te flessen, maar heb in mijn enthousiasme een verkeerde start gemaakt door direct met de vormgevende fase aan de slag te gaan. Ik ben gewoon dom geweest en zo voelt het ook.

Ik zal het PVA en het ontwikkeldossier conform jullie adviezen trachten aan te passen. Dit zal lastig zijn om dat de insteek en achtergrond een andere is. Daarom zit ik ook aan te denken een andere opdracht uit te werken, maar dat zou zonde zijn.

Ik wil nogmaals mijn excuses maken en betreur de gang van zaken (zoals het missen van de mails van Harry). Ik ben blij dat ik een nieuwe kans krijg. Zoals je (Henk) aangaf, zal dit na zomervakantie worden. Ik ben i.i.g. 100% gemotiveerd het volledig af te ronden.

Mijn vraag: Moet ik nog iets regelen om door te kunnen in het volgende schooljaar?

Mij rest nog jullie een fijne vakantie te wensen.

Met vriendelijke groeten,

Rense Veenstra  
Studentnummer: 1073458