MASTER THESIS

3D printed fiber reinforced lignin

Exploring the options to use wood in an additive manufacturing process

T.R.H. Liebrand

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ADDITIVE MANUFACTURING
RESEARCH QUESTION AND METHODOLOGY
WOOD THEORY

EXPERIMENT PHASE
PROTOTYPE PHASE
APPLICATIONS

CONCLUSION

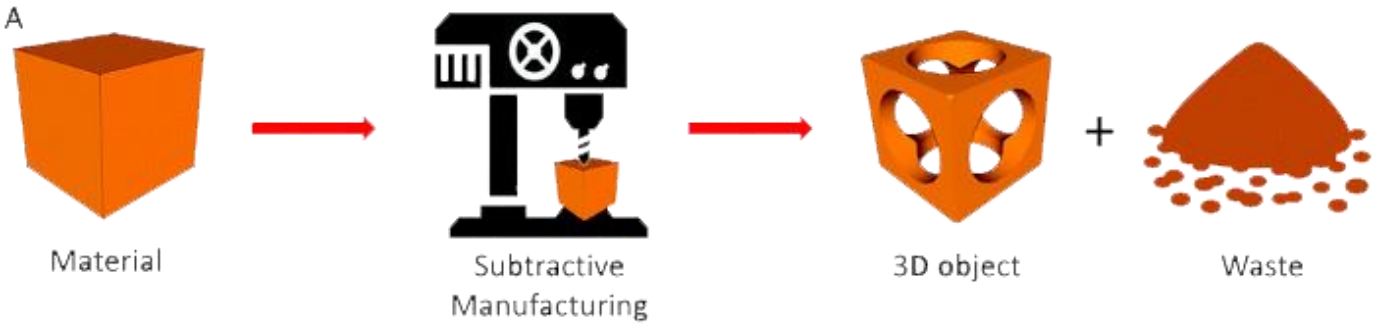
ADDITIVE MANUFACTURING

ADDITIVE MANUFACTURING

RAPID PROTOTYPING

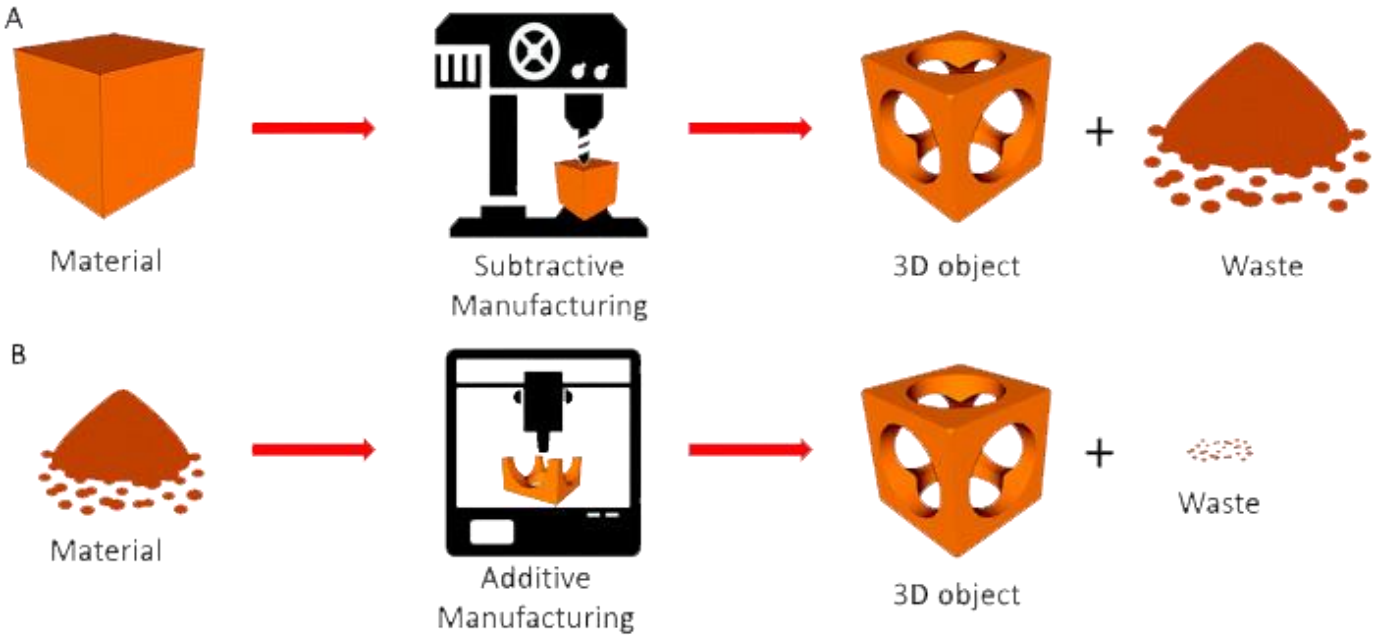
RAPID MANUFACTURING

3D PRINTING



- MILLING
- DRILLING
- CUTTING
- PLANING

ADDITIVE MANUFACTURING



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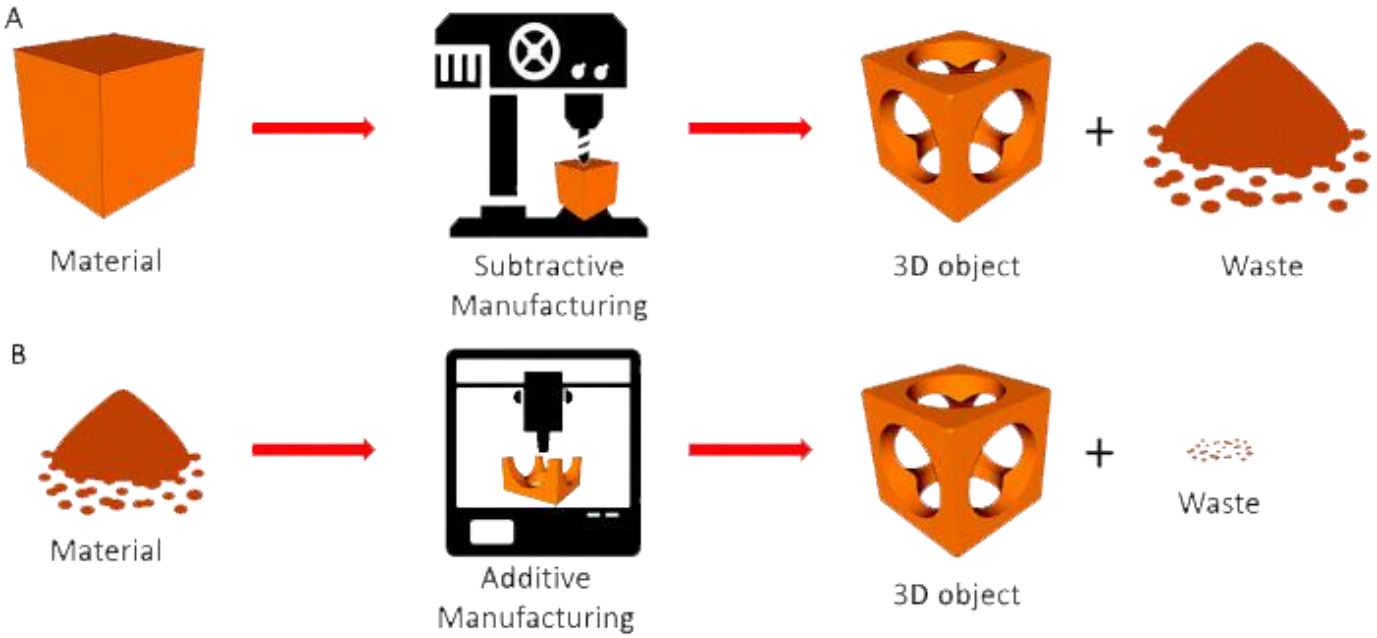

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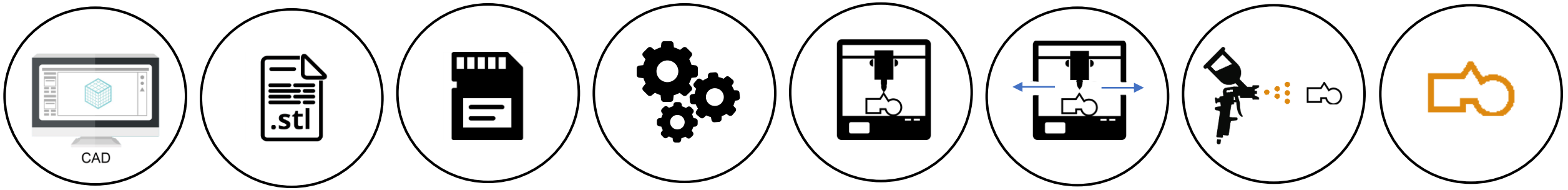
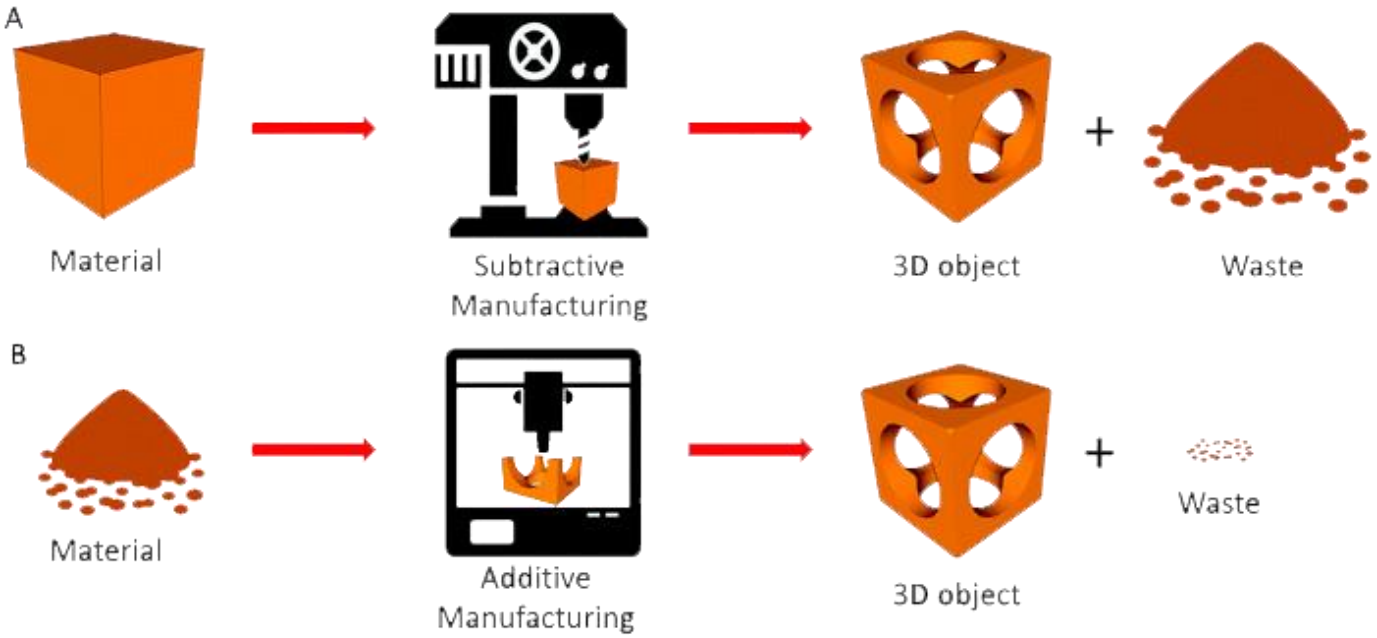
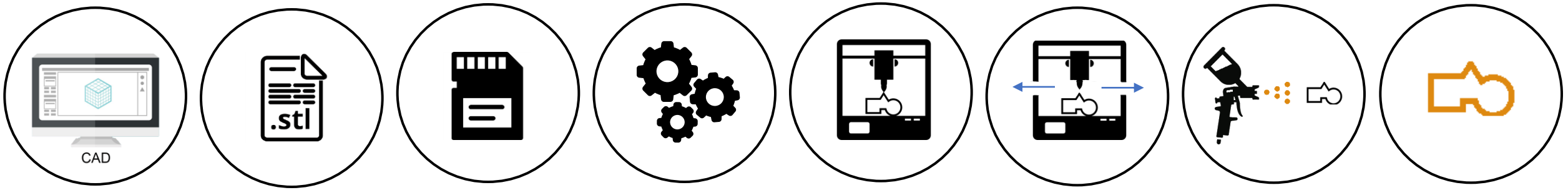
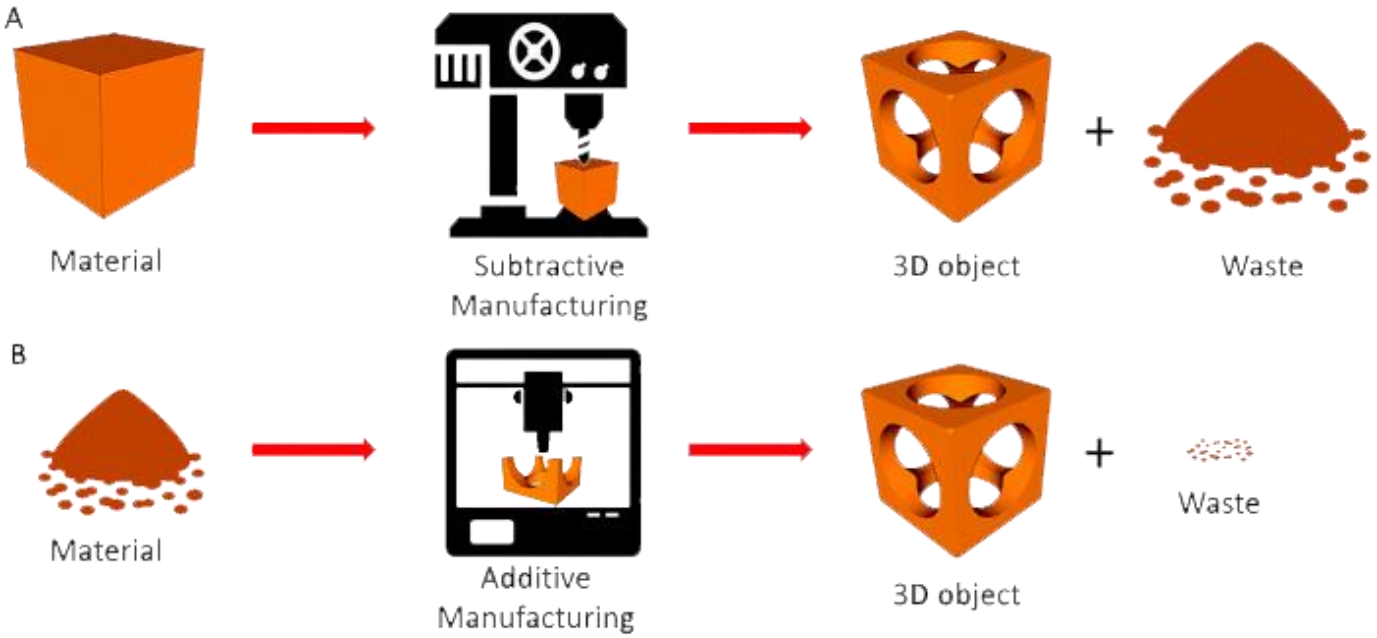




LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

ADDITIVE MANUFACTURING

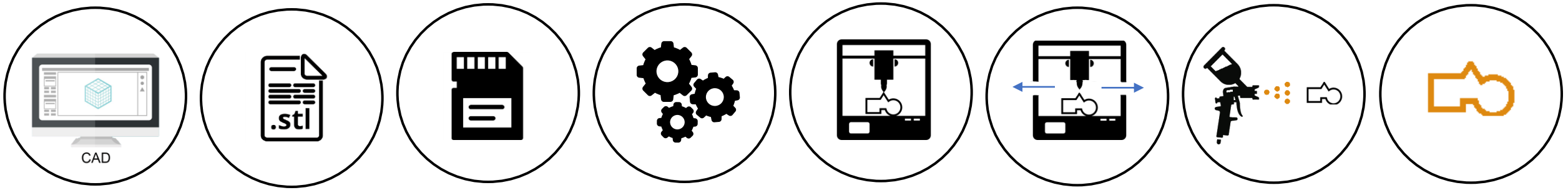


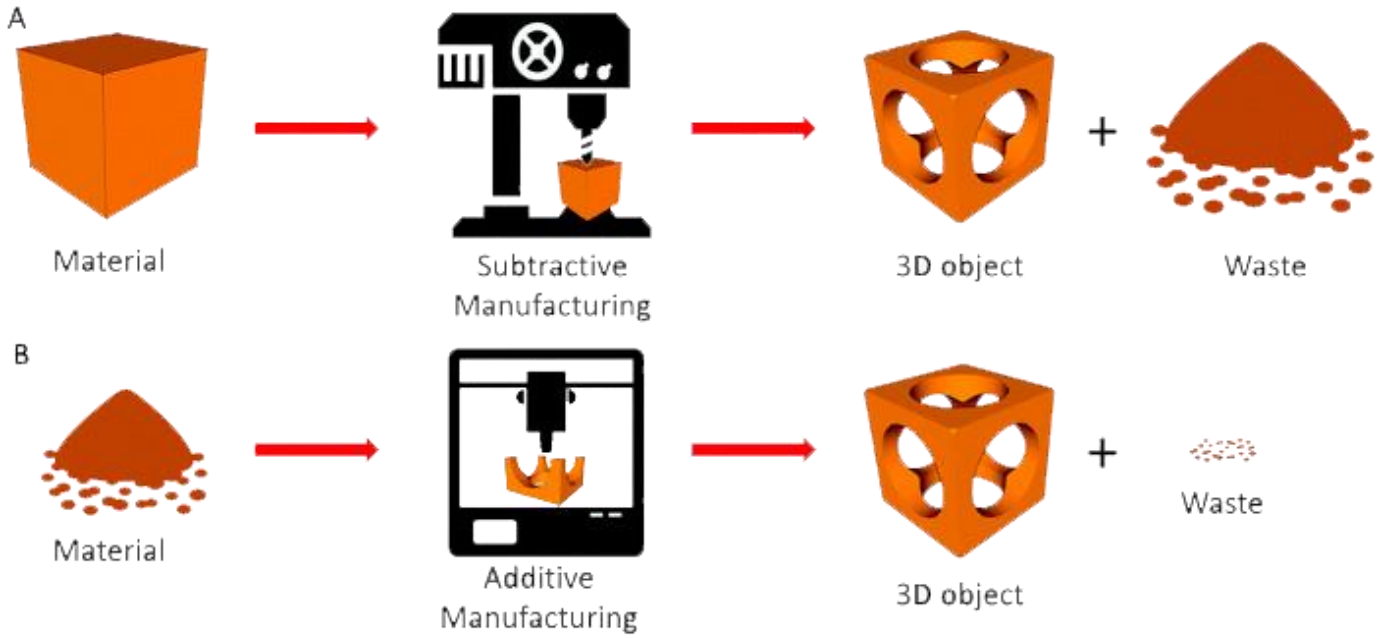


LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

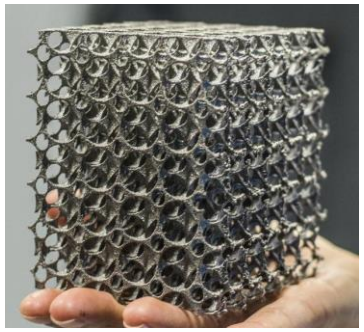
SLOW BUILD RATES
ONLY COST EFFECTIVE IN SMALL QUANTITIES
POST PROCESSING NEEDED
CONSTANT PRODUCTION COSTS

ADDITIVE MANUFACTURING





PLASTIC



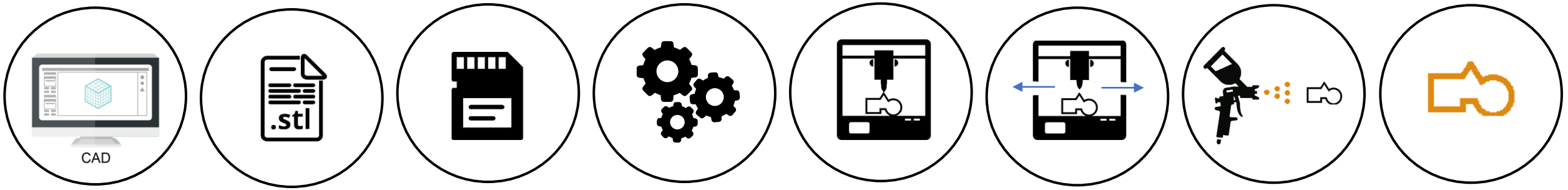
METALS

CONCRETE

?

WOOD

ADDITIVE MANUFACTURING



ADDITIVE MANUFACTURING

CONTAINS UP TO 60 % PLASTIC (PLA)

RESEARCH QUESTION

CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?

BACKGROUND QUESTIONS

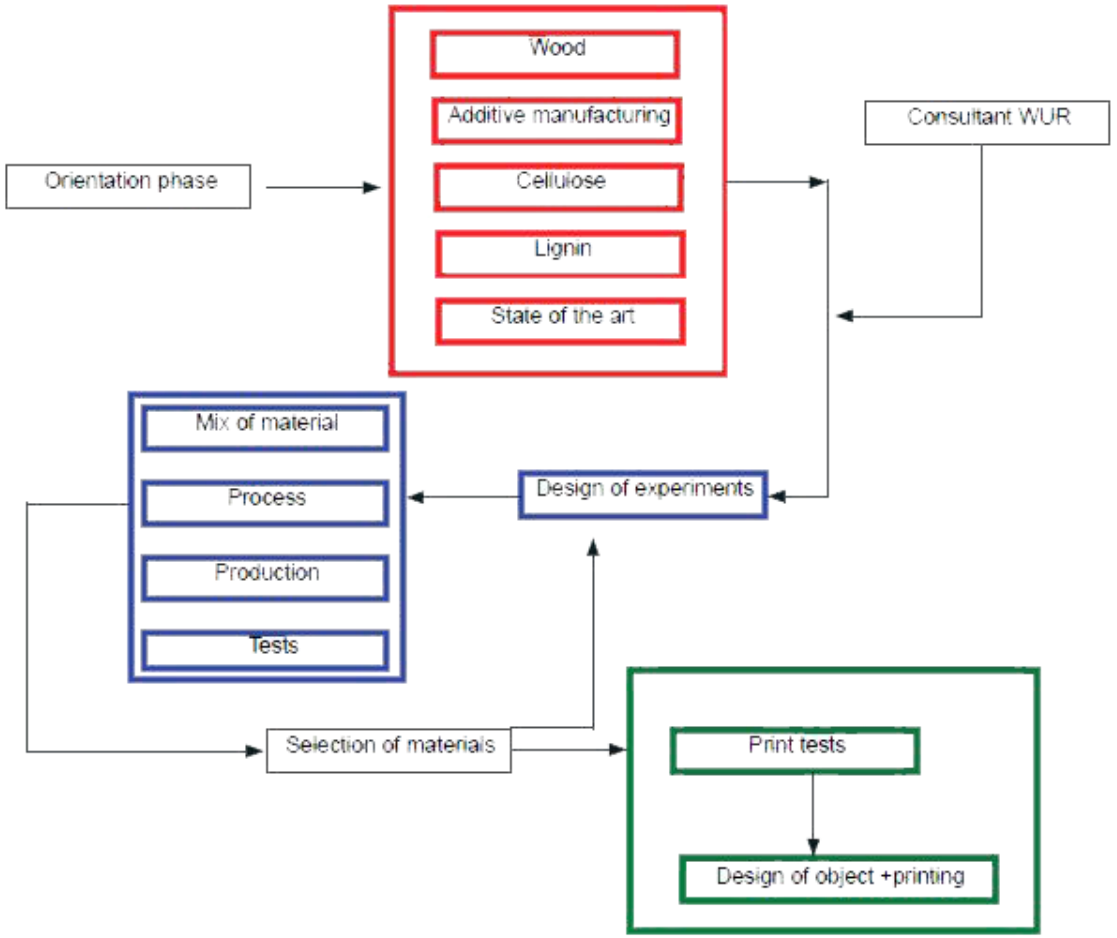
WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?

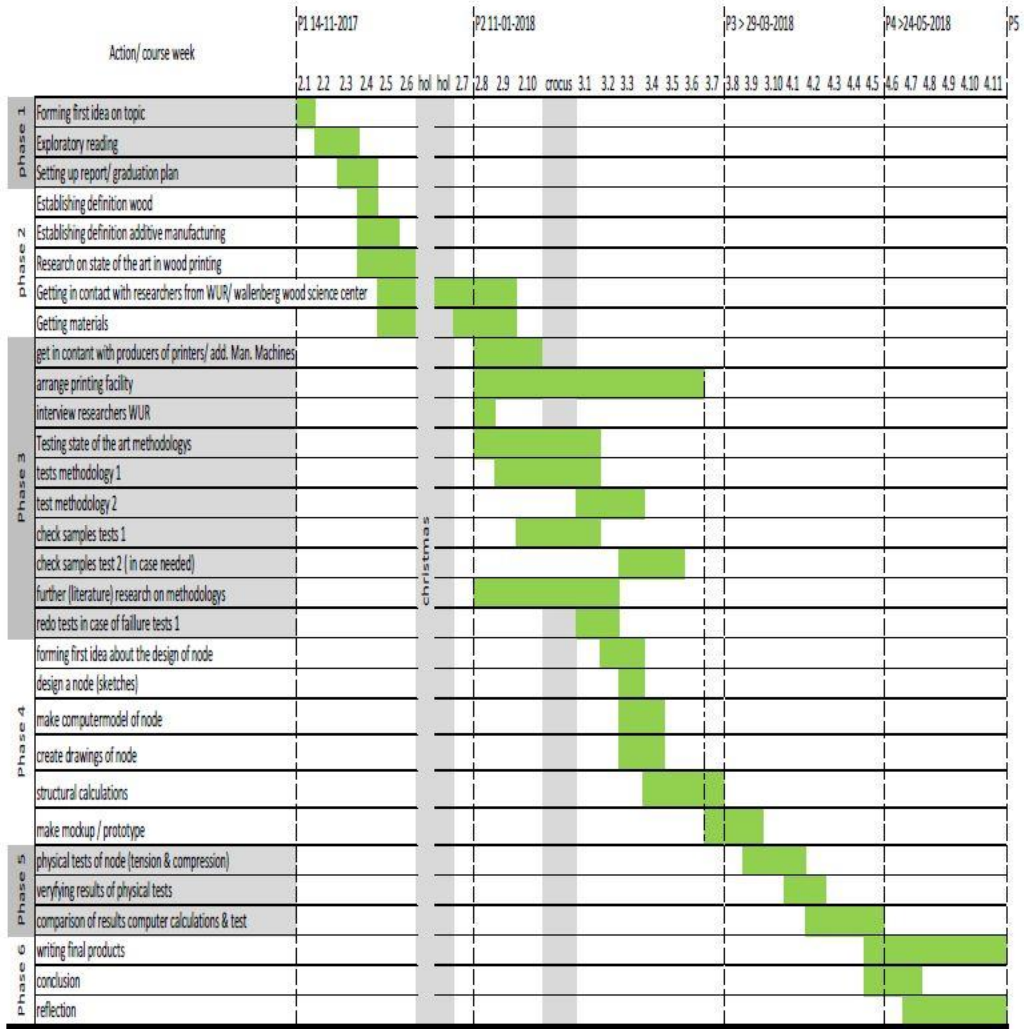
BACKGROUND QUESTIONS

WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?

HOW CAN THE COMPONENTS OF WOOD BE COMBINED IN A PRINTABLE MATERIAL?

RESEARCH METHODOLOGY





RESEARCH OUTPUT

EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

FABRICATION OF SAMPLES (SYRINGE BASED)

EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

DESIGN OF PROCESS

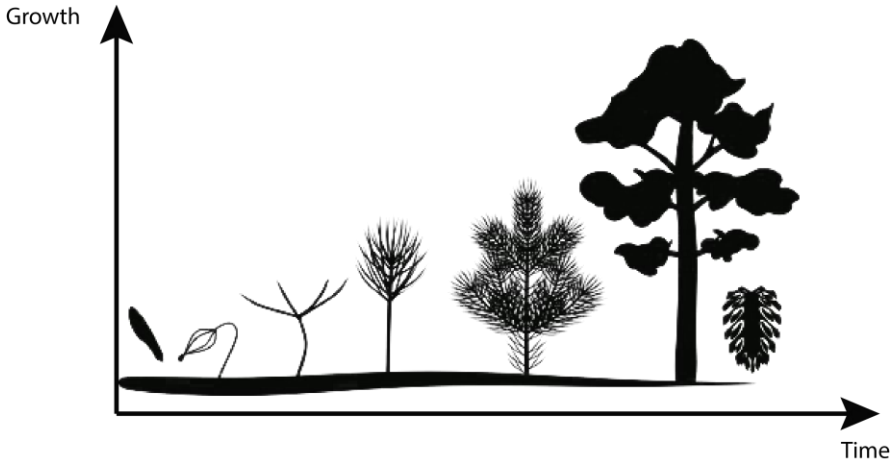
FABRICATION OF SAMPLES (SYRINGE BASED)

FABRICATION OF SAMPLES (3D printer BASED)

EXPLORING THE OPTIONS TO USE WOOD IN AN ADDITIVE MANUFACTURING PROCESS

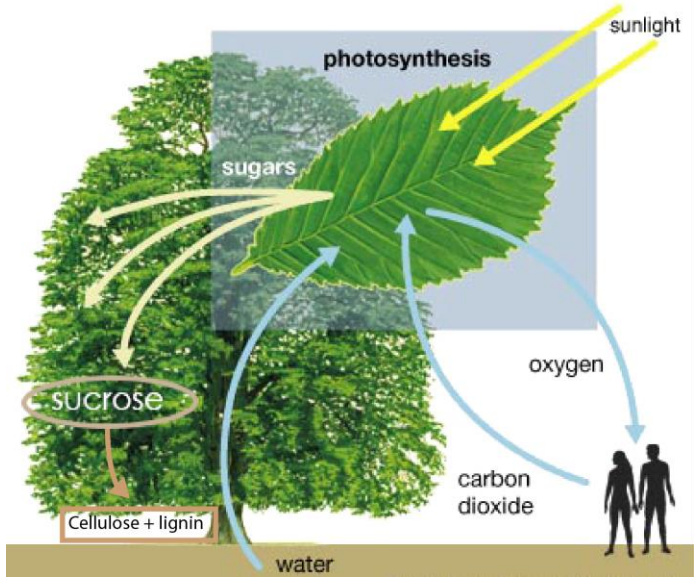
DESIGN OF PROCESS
FABRICATION OF SAMPLES (SYRINGE BASED)
FABRICATION OF SAMPLES (3D printer BASED)
PROOF OF PRINCIPLE

WOOD



WOOD

RESULT OF GROWTH CYCLE OF TREE



WOOD

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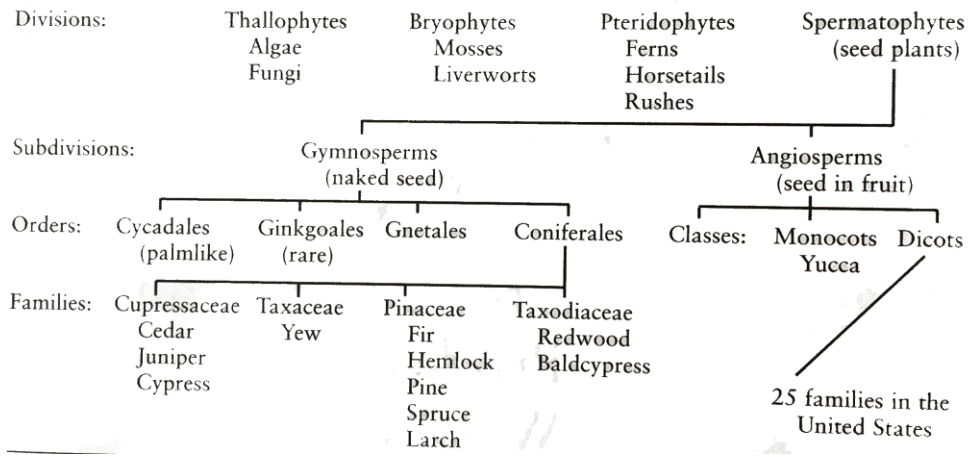
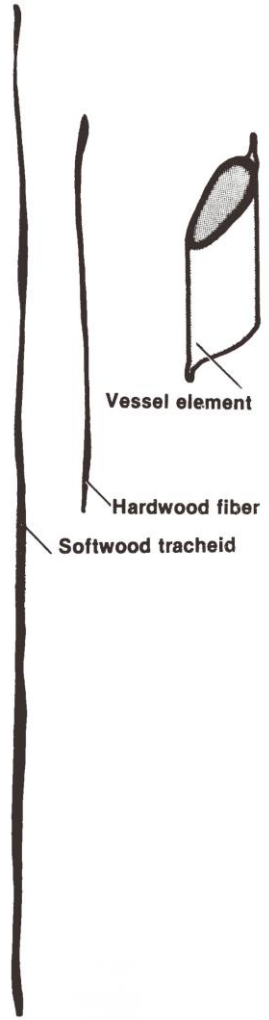
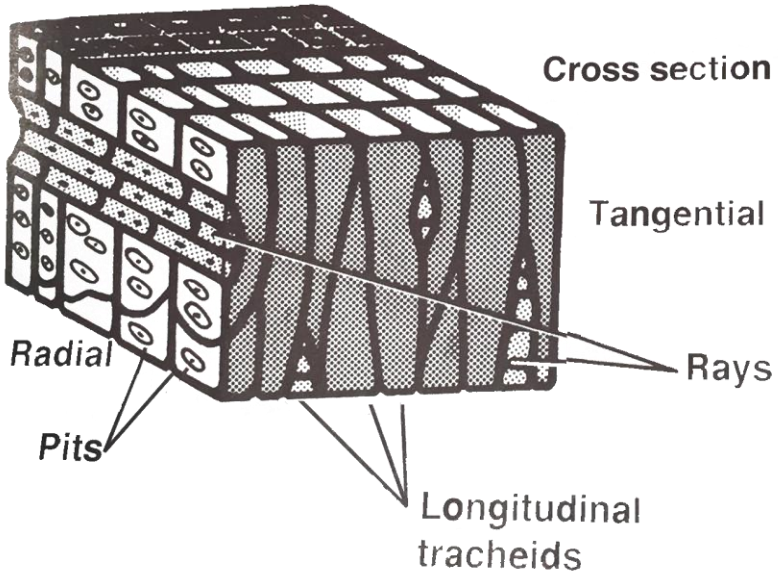


WOOD

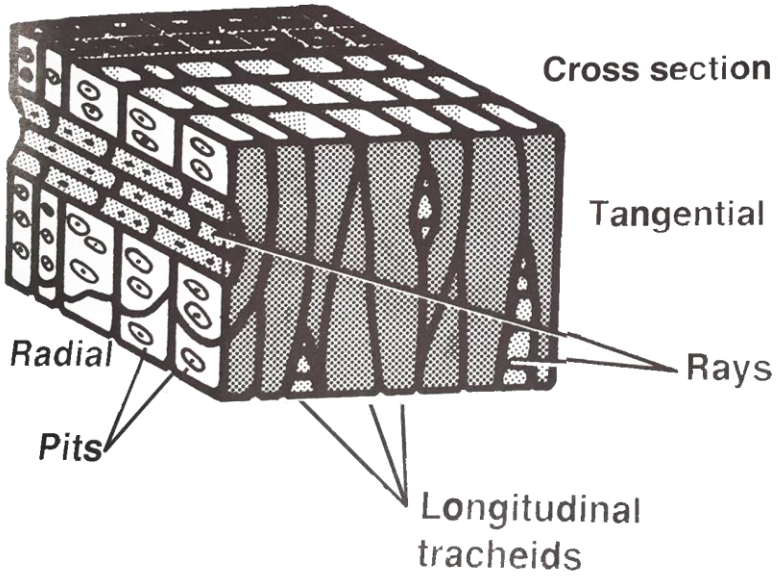
CELSTRUCTURE





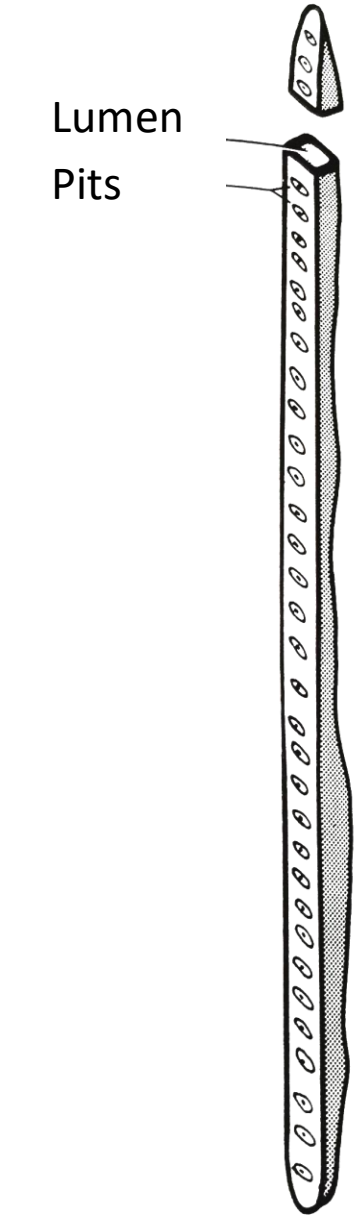
WOOD

CELSTRUCTURE



WOOD

CELSTRUCTURE

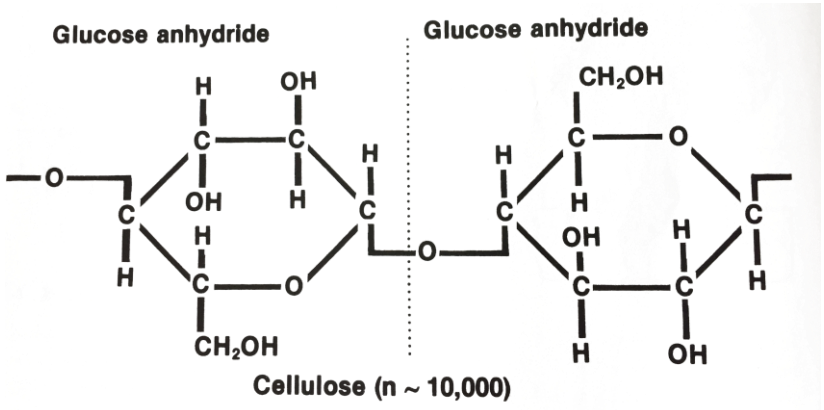


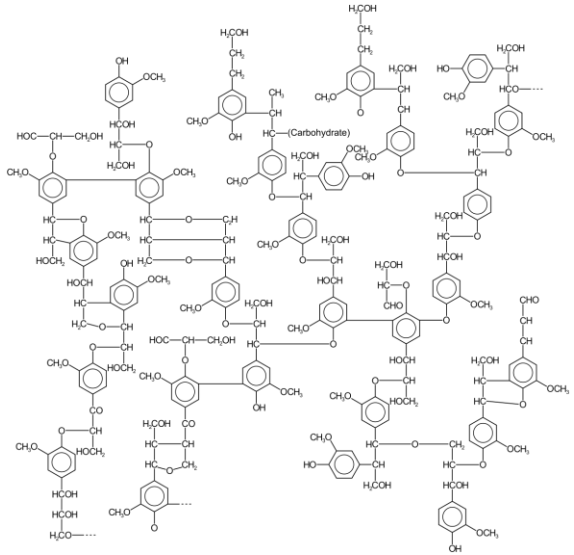
WOOD

CELLULOSE

WOOD

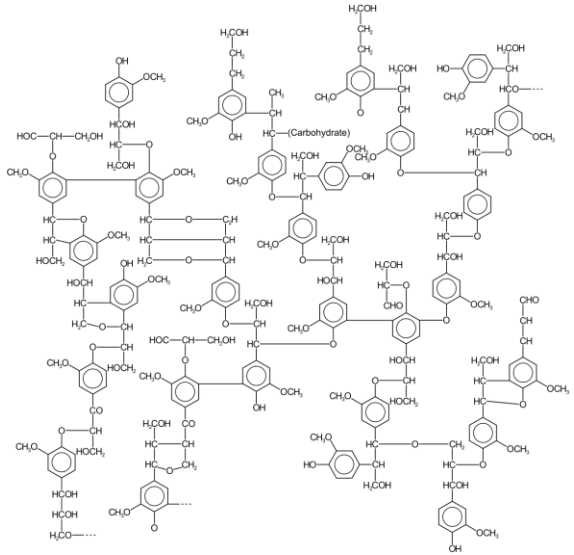
CELLULOSE





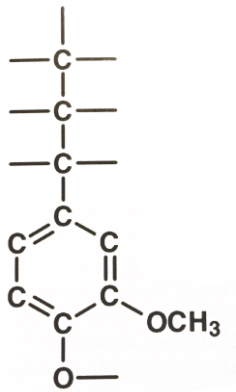
WOOD

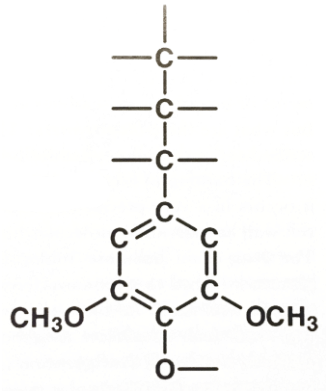
LIGNIN



WOOD

LIGNIN



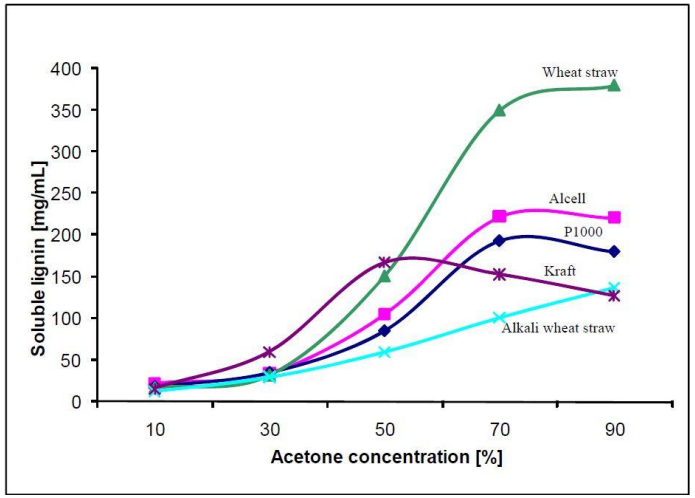


WOOD

LIGNIN

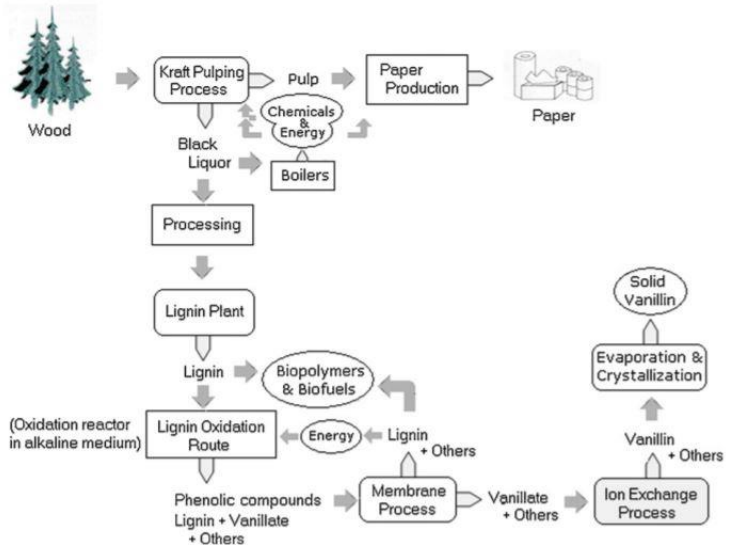
WOOD

LIGNIN


Soluble lignin [mg/mL]
400
350
300
250
200
150
100
50
0
10
30
50
70
90
Acetone concentration [%]
Wheat straw
Alcell
P1000
Kraft
Alkali wheat straw

WOOD

LIGNIN


Wood
Kraft Pulping Process
Pulp
Paper Production
Paper
Chemicals & Energy
Black Liquor
Boilers
Processing
Lignin Plant
Lignin
Biopolymers & Biofuels
(Oxidation reactor in alkaline medium)
Lignin Oxidation Route
Energy
Lignin + Others
Phenolic compounds Lignin + Vanillate + Others
Membrane Process
Vanillate + Others
Ion Exchange Process
Vanillin + Others
Evaporation & Crystallization
Solid Vanillin

WOOD

LIGNIN

EXPERIMENTS

EXPERIMENTS

EXPERIMENTS

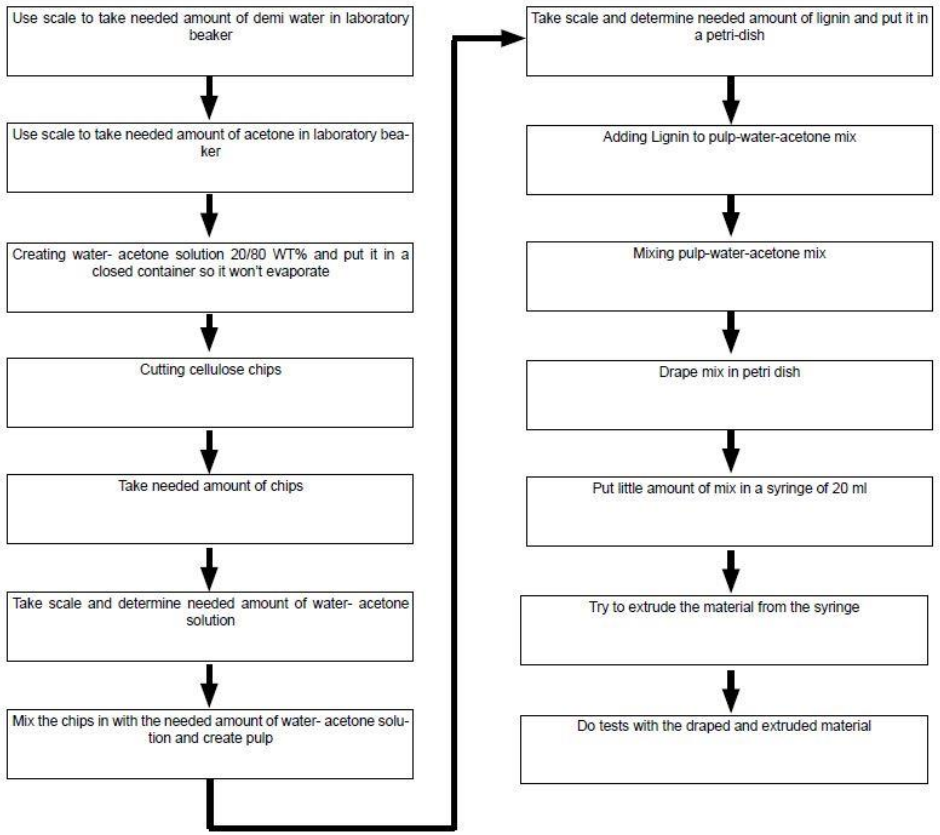
IDEA

+

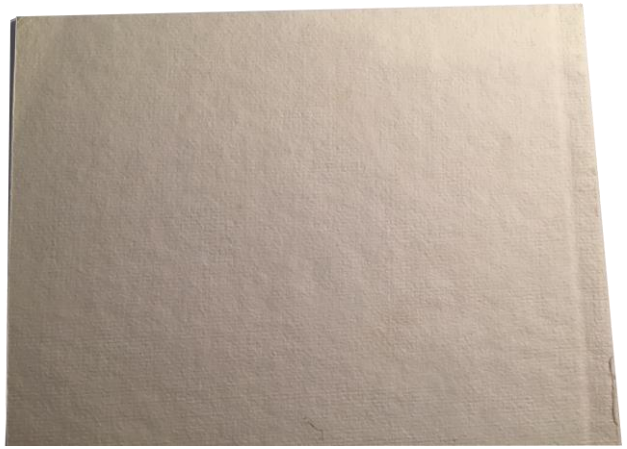
ACETONE 80%
WATER 20%

+

PROCESS


Use scale to take needed amount of demi water in laboratory beaker
Use scale to take needed amount of acetone in laboratory beaker
Creating water- acetone solution 20/80 WT% and put it in a closed container so it won't evaporate
Cutting cellulose chips
Take needed amount of chips
Take scale and determine needed amount of water- acetone solution
Mix the chips in with the needed amount of water- acetone solution and create pulp
Take scale and determine needed amount of lignin and put it in a petri-dish
Adding Lignin to pulp-water-acetone mix
Mixing pulp-water-acetone mix
Drape mix in petri dish
Put little amount of mix in a syringe of 20 ml
Try to extrude the material from the syringe
Do tests with the draped and extruded material

EXPERIMENTS

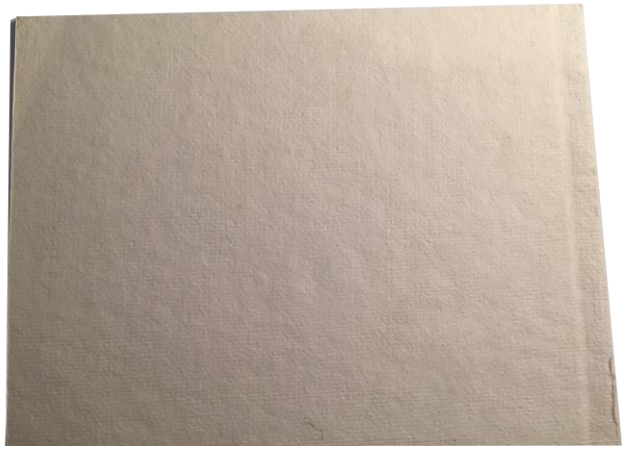


SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN

EXPERIMENTS

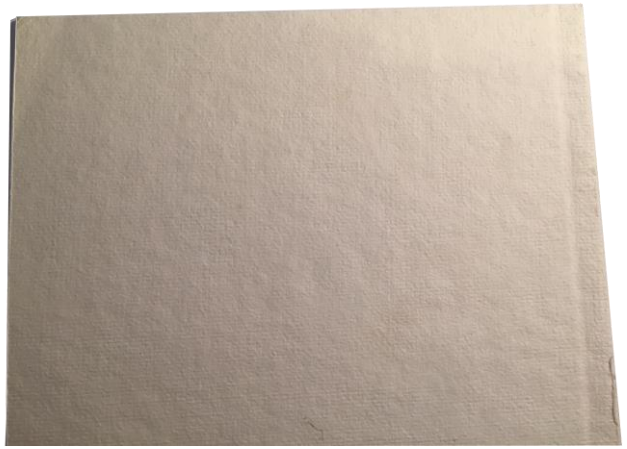
HOW TO GET FIBERS?



SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN

EXPERIMENTS
HOW TO GET FIBERS?
PULPING



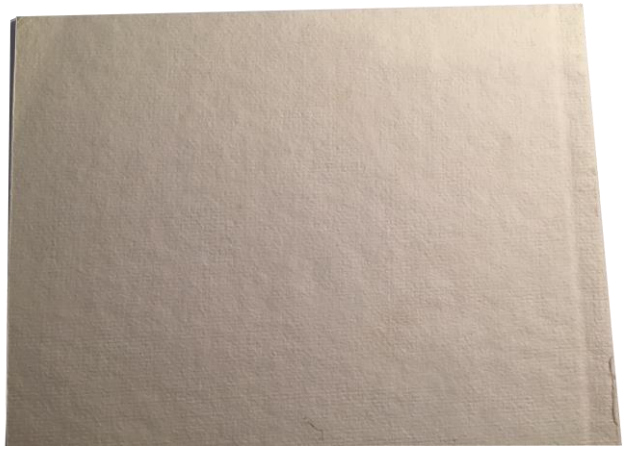
SKOGCELL 90Z BLEACHED KRAFT WFBR

INDULIN AT KRAFT LIGNIN

EXPERIMENTS

HOW TO GET FIBERS?

PULPING



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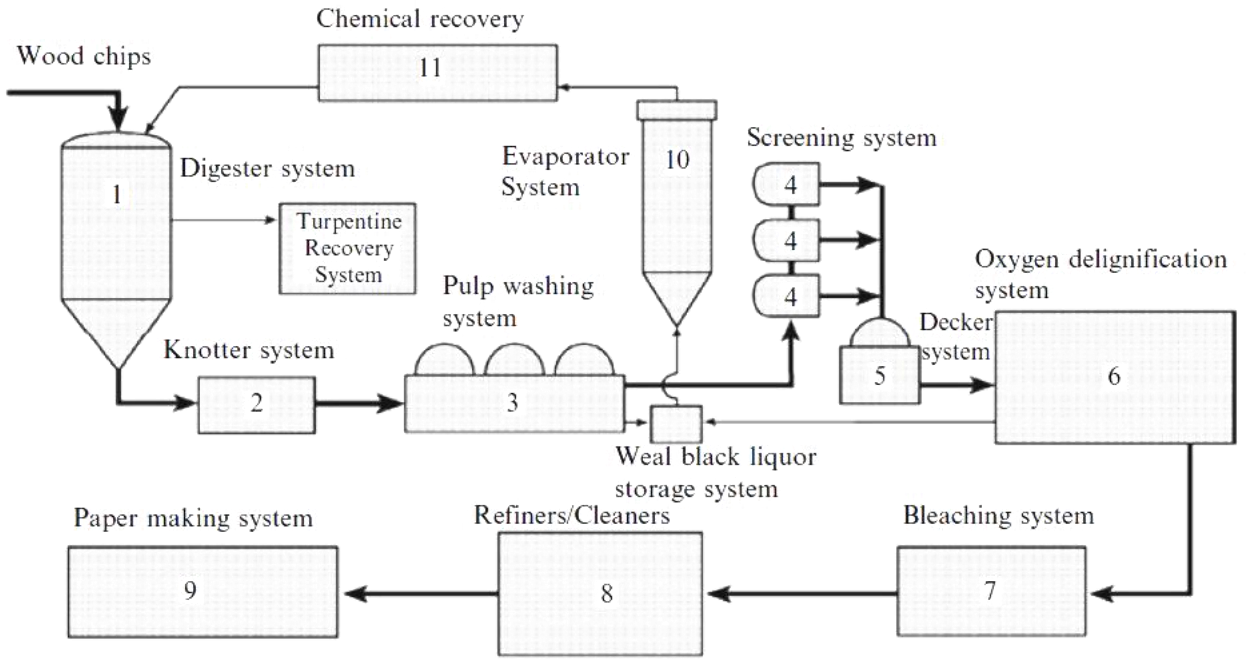
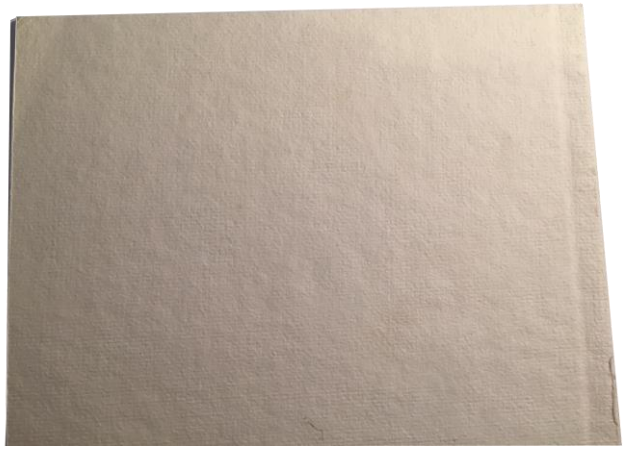
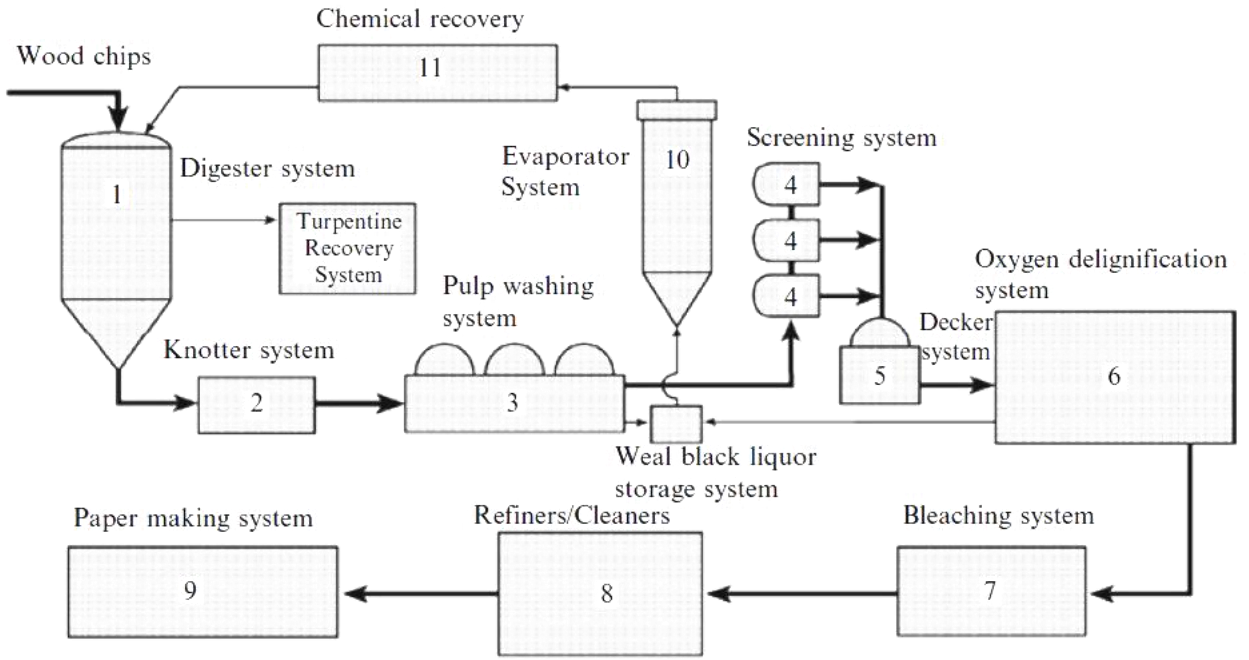


EXPERIMENTS
HOW TO GET FIBERS?
PULPING

ACETONE 80%
WATER 20%



SKOGCELL 90Z BLEACHED KRAFT WFBR



CHIPPED SKOGCELL 90Z BLEACHED KRAFT WFBR

EXPERIMENTS

PULPING

EXPERIMENTS

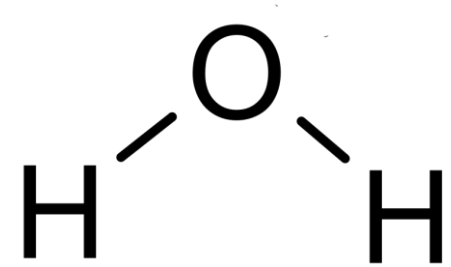
PULPING

AFTER 48 HOURS

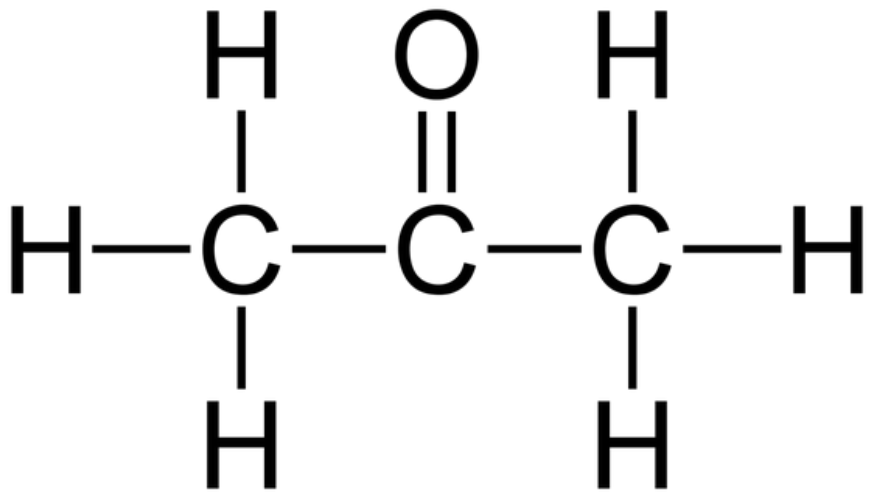
EXPERIMENTS

PULPING

AFTER 48 HOURS

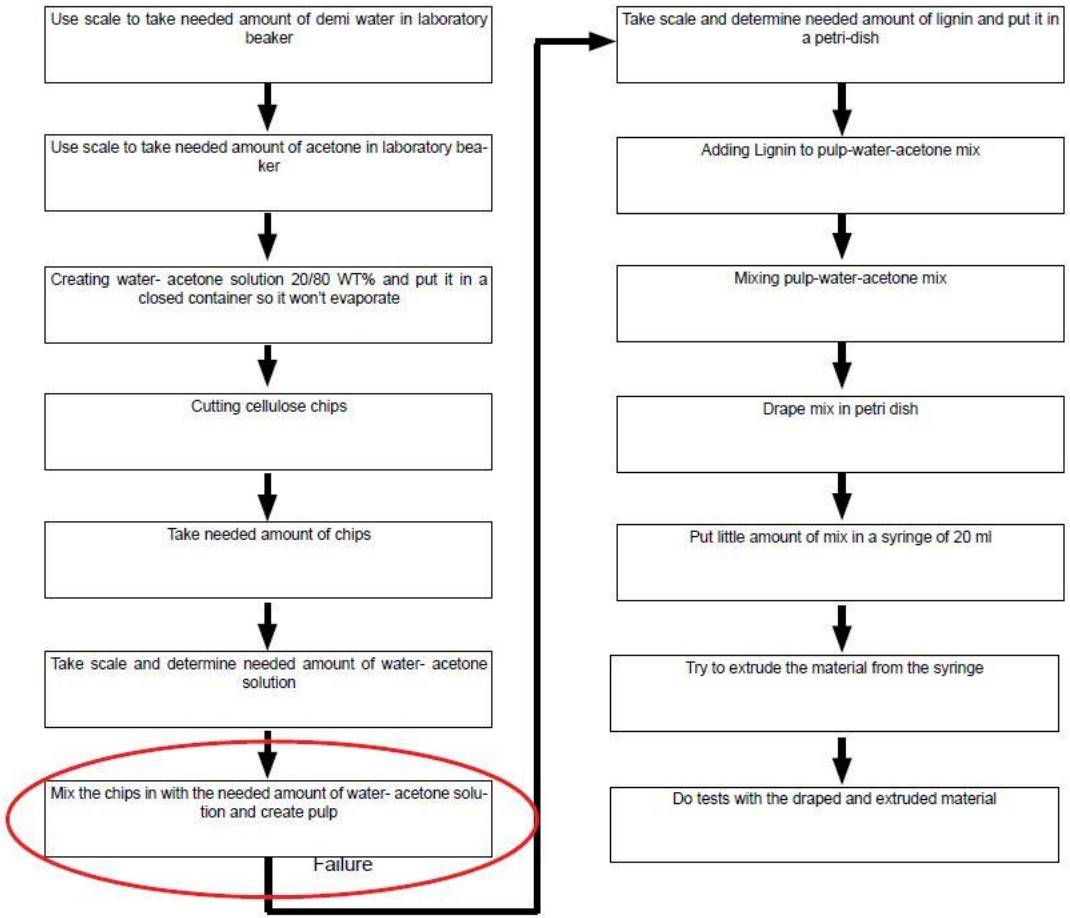


WATER



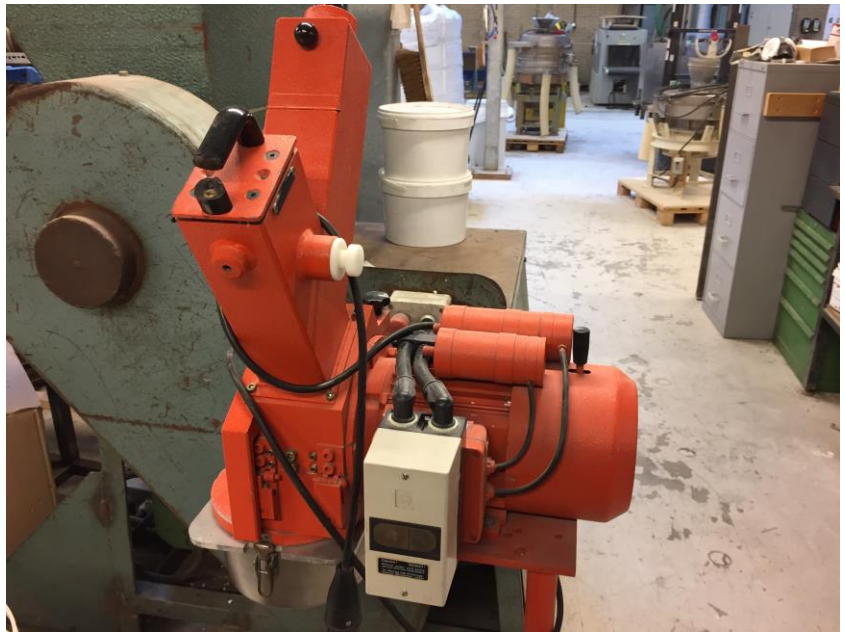
ACETONE

PROCESS

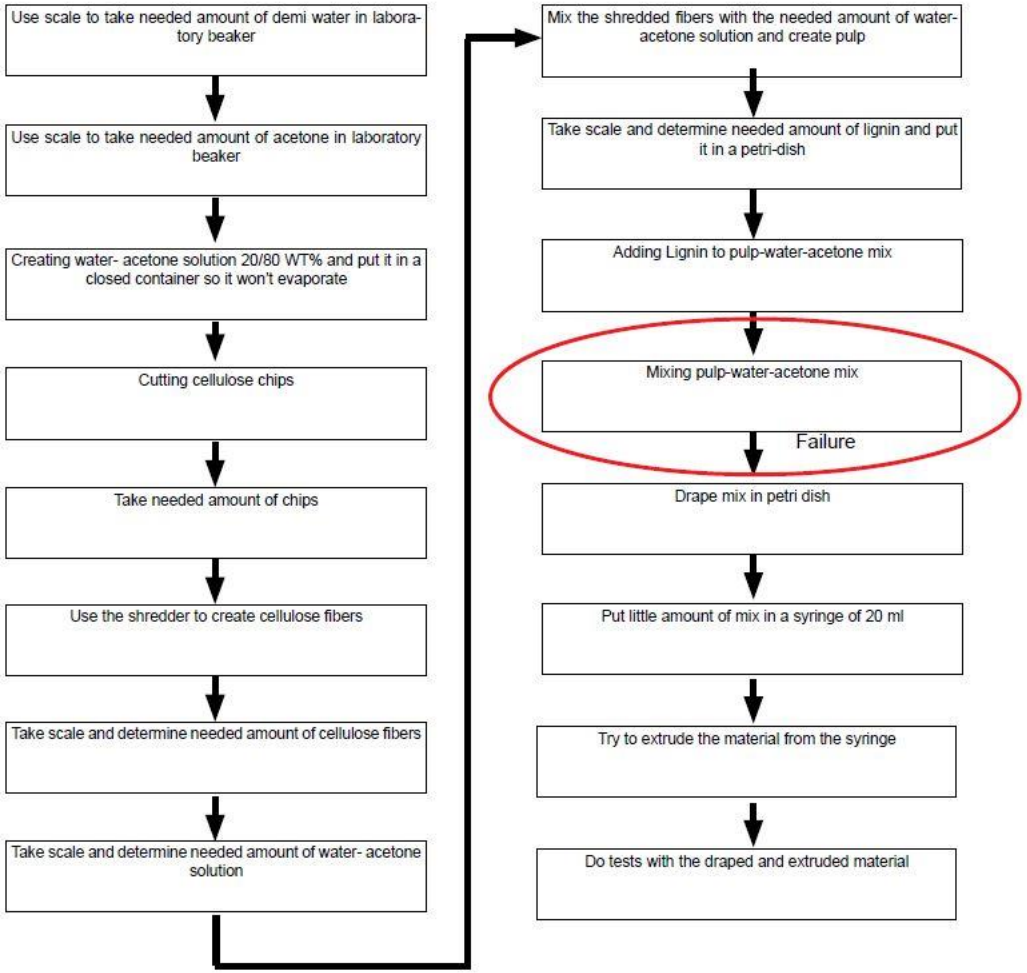

Use scale to take needed amount of demi water in laboratory beaker
Use scale to take needed amount of acetone in laboratory beaker
Creating water- acetone solution 20/80 WT% and put it in a closed container so it won't evaporate
Cutting cellulose chips
Take needed amount of chips
Take scale and determine needed amount of water- acetone solution
Mix the chips in with the needed amount of water- acetone solution and create pulp
Failure
Take scale and determine needed amount of lignin and put it in a petri-dish
Adding Lignin to pulp-water-acetone mix
Mixing pulp-water-acetone mix
Drape mix in petri dish
Put little amount of mix in a syringe of 20 ml
Try to extrude the material from the syringe
Do tests with the draped and extruded material

EXPERIMENTS

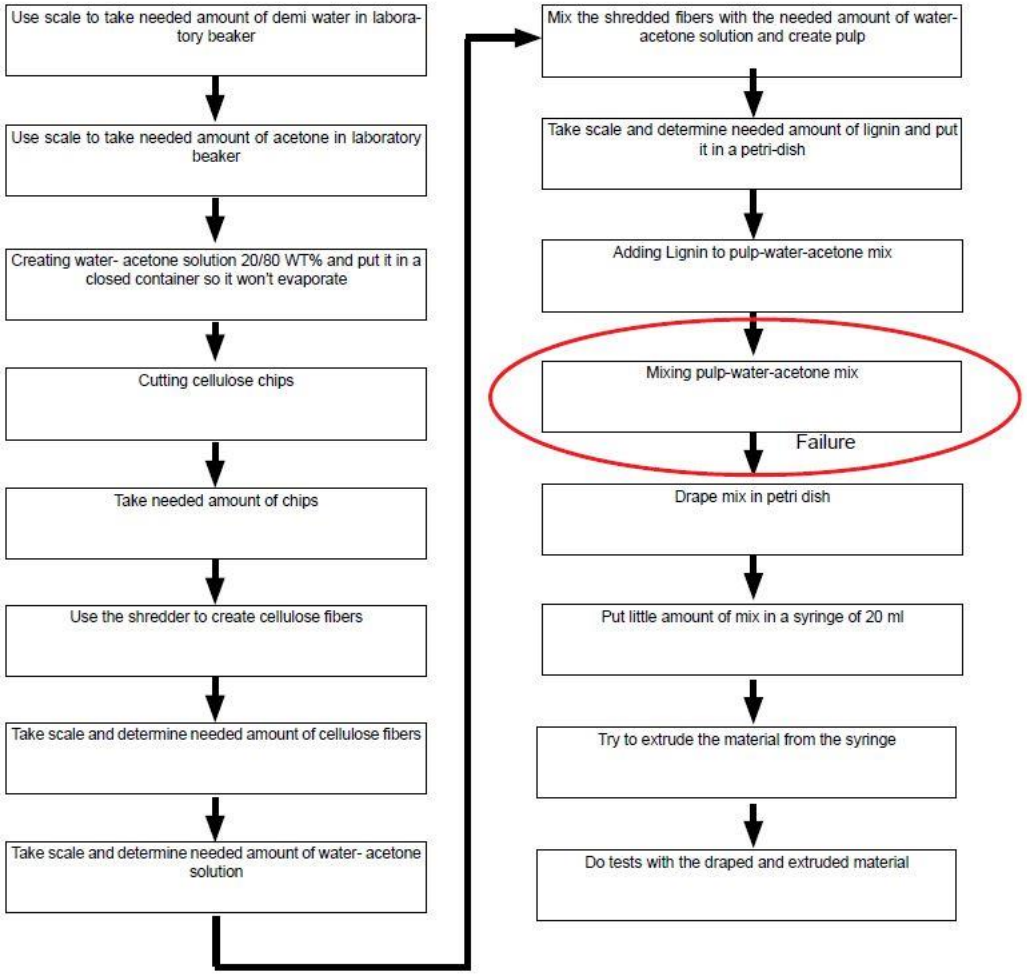
PROCESS

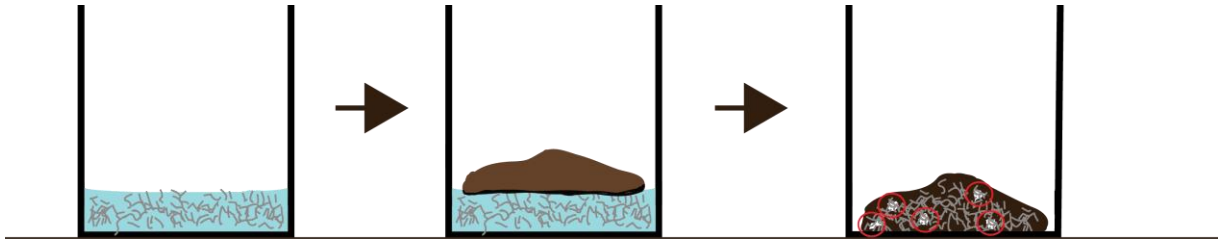


PROCESS


Use scale to take needed amount of demi water in labora-tory beaker
Use scale to take needed amount of acetone in laboratory beaker
Creating water- acetone solution 20/80 WT% and put it in a closed container so it won't evaporate
Cutting cellulose chips
Take needed amount of chips
Use the shredder to create cellulose fibers
Take scale and determine needed amount of cellulose fibers
Take scale and determine needed amount of water- acetone solution
Mix the shredded fibers with the needed amount of water-acetone solution and create pulp
Take scale and determine needed amount of lignin and put it in a petri-dish
Adding Lignin to pulp-water-acetone mix
Mixing pulp-water-acetone mix
Failure
Drape mix in petri dish
Put little amount of mix in a syringe of 20 ml
Try to extrude the material from the syringe
Do tests with the draped and extruded material

PROCESS

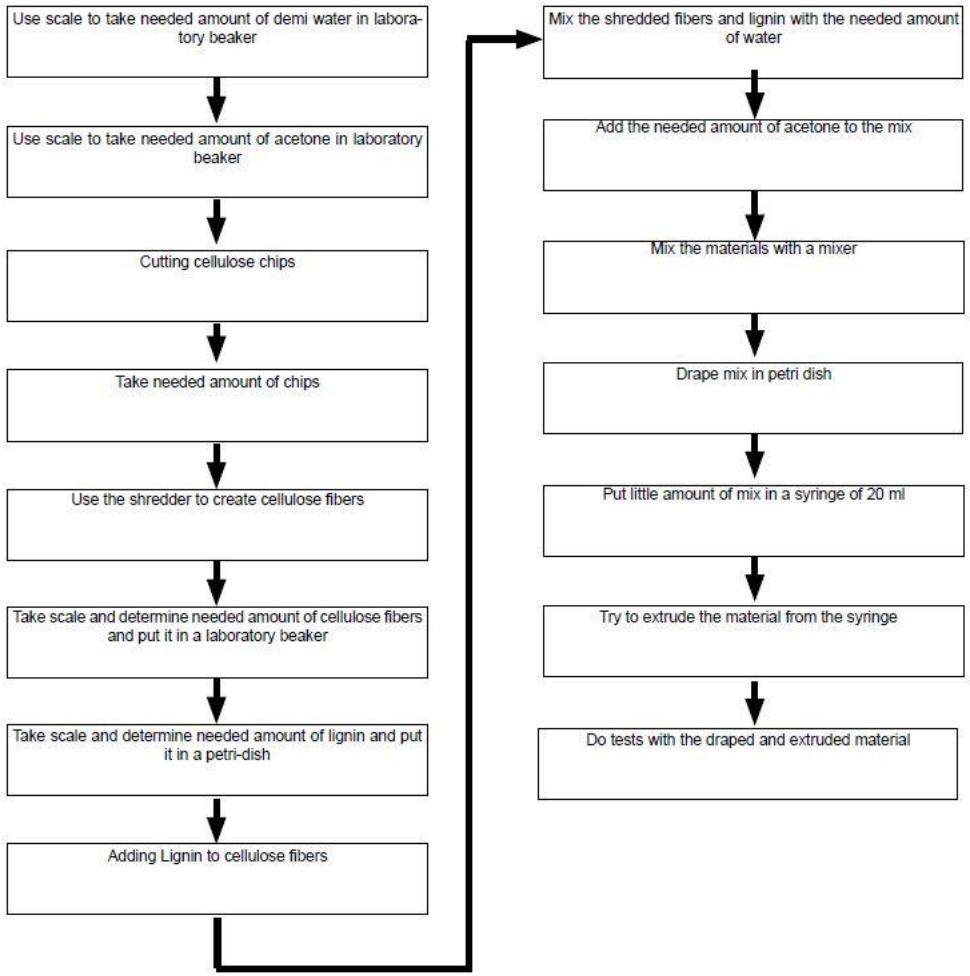




RESULT: CELLULOSE INCLUSIONS IN MATERIAL MIX

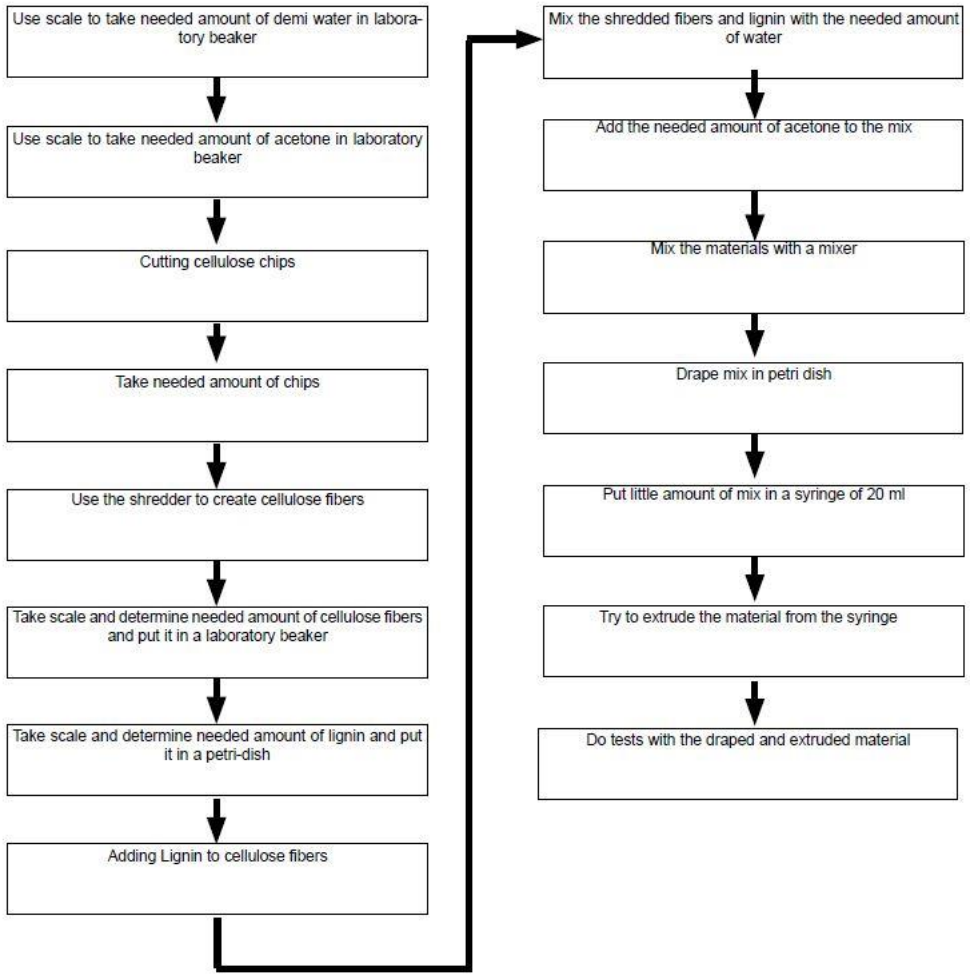
PROBLEMS WITH EXTRUSION

PROCESS



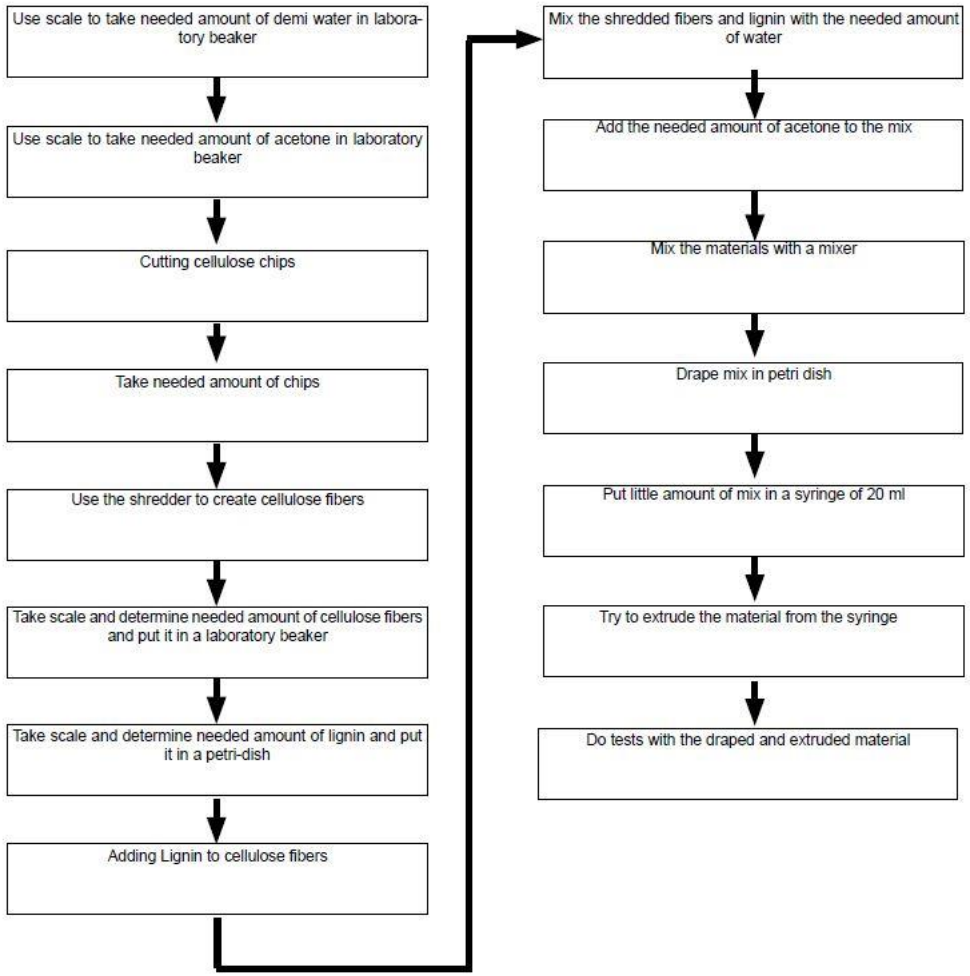
- MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE

PROCESS



- MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE

PROCESS



- MIXING CELLULOSE WITH LIGNIN IN NEARLY DRY STATE

- DRY MIX COMBINED WITH ACETONE WATER SOLUTION

MATERIAL SAMPLES

Sample 1
Lignin 20gr
Cellulose 5 gr
Cellulose 20%

Fluid 80gr
20/80 (h2o/acetone)

Sample 2
Lignin 5 gr
Cellulose 7,5 gr
Cellulose 60%

Fluid 75gr
20/80 (h2o/acetone)

Sample 3
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%

Fluid 75 gr
20/80 (h2o/acetone)

Sample 4
Lignin 7,5 gr
Cellulose 5 gr
Cellulose 40%

Fluid 75 gr
20/80 (h2o/acetone)

Sample 5
Lignin 11 gr
Cellulose 1 gr
Cellulose 8,3%

Fluid 75 gr
20/80 (h2o/acetone)

MATERIAL SAMPLES

Sample 1
Lignin 20gr
Cellulose 5 gr
Cellulose 20%

Fluid 80gr
20/80 (h2o/acetone)

Sample 2
Lignin 5 gr
Cellulose 7,5 gr
Cellulose 60%

Fluid 75gr
20/80 (h2o/acetone)

Sample 3
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%

Fluid 75 gr
20/80 (h2o/acetone)

Sample 4
Lignin 7,5 gr
Cellulose 5 gr
Cellulose 40%

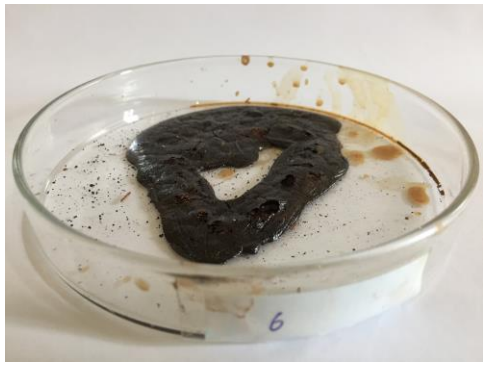
Fluid 75 gr
20/80 (h2o/acetone)

Sample 5
Lignin 11 gr
Cellulose 1 gr
Cellulose 8,3%

Fluid 75 gr
20/80 (h2o/acetone)

- TOO MUCH FLUID
- NON HOMOGENEOUS
- LOW ADHESIVE STRENGTH
- NOT EXTRUDABLE

MATERIAL SAMPLES



Sample 6
Lignin 10 gr
Cellulose 0 gr

Fluid 10 gr
0/100 (h2o/acetone)

MATERIAL SAMPLES

Sample 7
Lignin 40 gr
Cellulose 1 gr
Cellullose 2,4 %

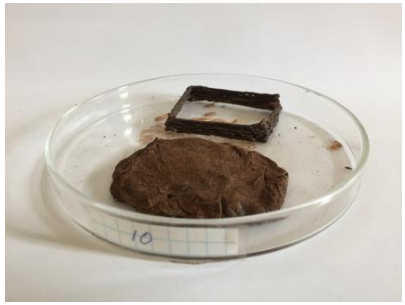
Fluid 60 gr
66,6/33,3 (h2o/acetone)

Sample 8
Lignin 40 gr
Cellulose 3 gr
Cellulose 6,98%

Fluid 60 gr
66,6/33,3 (h2o/acetone)

Sample 9
Lignin 40 gr
Cellulose 4 gr
Cellulose 9,09 %

Fluid 42 gr
61,9/38,1 (h2o/acetone)



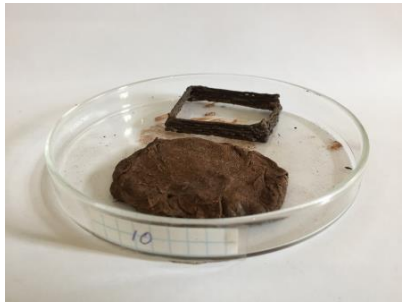
Sample 10
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1%

Fluid 46 gr
43,5/56,5 (h2o/acetone)

Sample 11
Lignin 40 gr
Cellulose 10 gr
Cellulose 20%

Fluid 75 gr
60/40 (h2o/acetone)

MATERIAL SAMPLES



Sample 7
Lignin 40 gr
Cellulose 1 gr
Cellullose 2,4 %

Fluid 60 gr
66,6/33,3 (h2o/acetone)

Sample 8
Lignin 40 gr
Cellulose 3 gr
Cellulose 6,98%

Fluid 60 gr
66,6/33,3 (h2o/acetone)

Sample 9
Lignin 40 gr
Cellulose 4 gr
Cellulose 9,09 %

Fluid 42 gr
61,9/38,1 (h2o/acetone)

Sample 10
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1%

Fluid 46 gr
43,5/56,5 (h2o/acetone)

Sample 11
Lignin 40 gr
Cellulose 10 gr
Cellulose 20%

Fluid 75 gr
60/40 (h2o/acetone)

- IMPROVED HOMOGENEITY
- FIRST EXTRUDED SAMPLES WITH GOOD RESULT
- LIGNIN USED AS MEDIUM FOR EXTRUSION

MATERIAL SAMPLES

Sample 12
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%

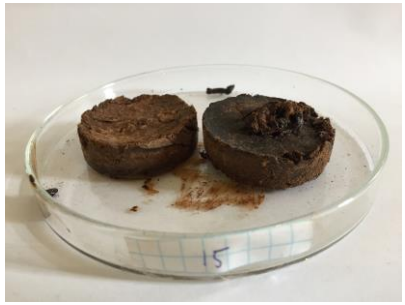
Fluid 15 gr
33,3/66,6 (h2o/acetone)

Sample 13
Lignin 10 gr
Cellulose 2 gr
Cellulose 16,67%

Fluid 6,5 gr
23,1/76,9 (h2o/acetone)

Sample 14
Lignin 8 gr
Cellulose 4 gr
Cellulose 33,33%

Fluid 19 gr
31,6/68,4 (h2o/acetone)



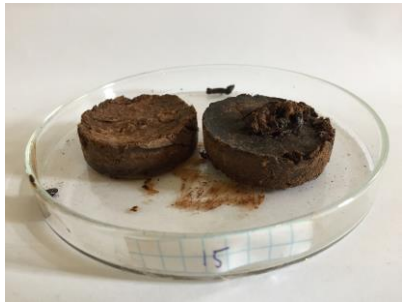
Sample 15
Lignin 10 gr
Cellulose 4 gr
Cellulose 28,57%

Fluid 21 gr
28,6/71,4 (h2o/acetone)

Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%

Fluid 86 gr
46,5/53,5 (h2o/acetone)

MATERIAL SAMPLES



Sample 12
Lignin 10 gr
Cellulose 2,5 gr
Cellulose 20%

Fluid 15 gr
33,3/66,6 (h2o/acetone)

Sample 13
Lignin 10 gr
Cellulose 2 gr
Cellulose 16,67%

Fluid 6,5 gr
23,1/76,9 (h2o/acetone)

Sample 14
Lignin 8 gr
Cellulose 4 gr
Cellulose 33,33%

Fluid 19 gr
31,6/68,4 (h2o/acetone)

Sample 15
Lignin 10 gr
Cellulose 4 gr
Cellulose 28,57%

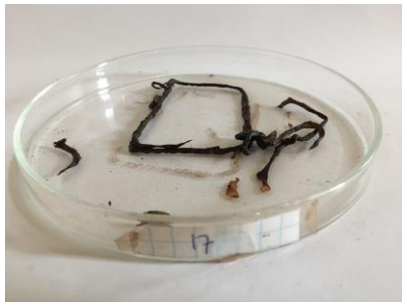
Fluid 21 gr
28,6/71,4 (h2o/acetone)

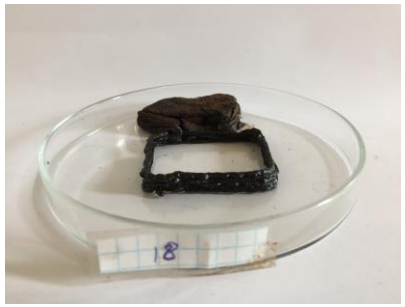
Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%

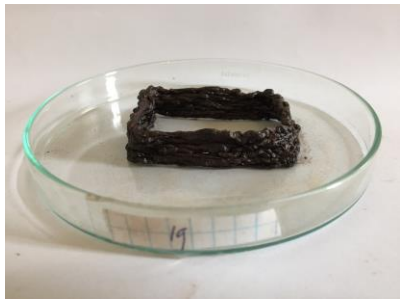
Fluid 86 gr
46,5/53,5 (h2o/acetone)

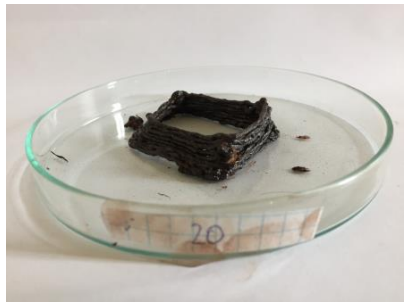
- TOO MUCH CELLULOSE RESULTED IN EXTRUSION PROBLEMS
- TOOLS NEEDED IN ORDER TO EXTRUDE SAMPLES

MATERIAL SAMPLES









Sample 17
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1%

Fluid 27 gr
18,52 /81,5 (h2o/acetone)

Sample 18
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1%

Fluid 36 gr
27,8/72,2 (h2o/acetone)

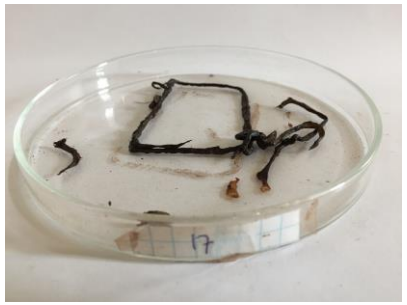
Sample 19
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1 %

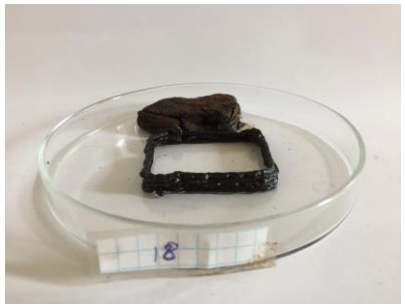
Fluid 32 gr
31,2/68,8 (h2o/acetone)

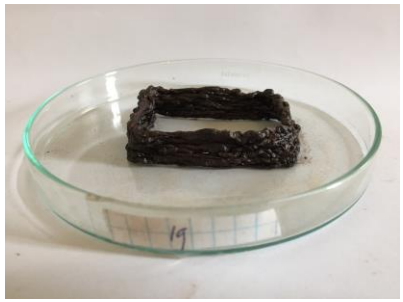
Sample 20
Lignin 60 gr
Cellulose 5 gr
Cellulose 7,69%

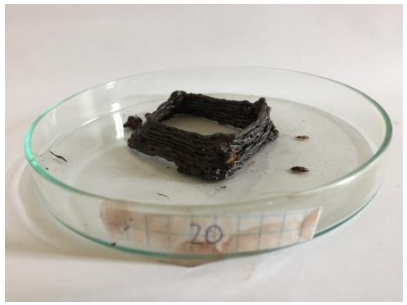
Fluid 38 gr
26,3/73,7 (h2o/acetone)

MATERIAL SAMPLES







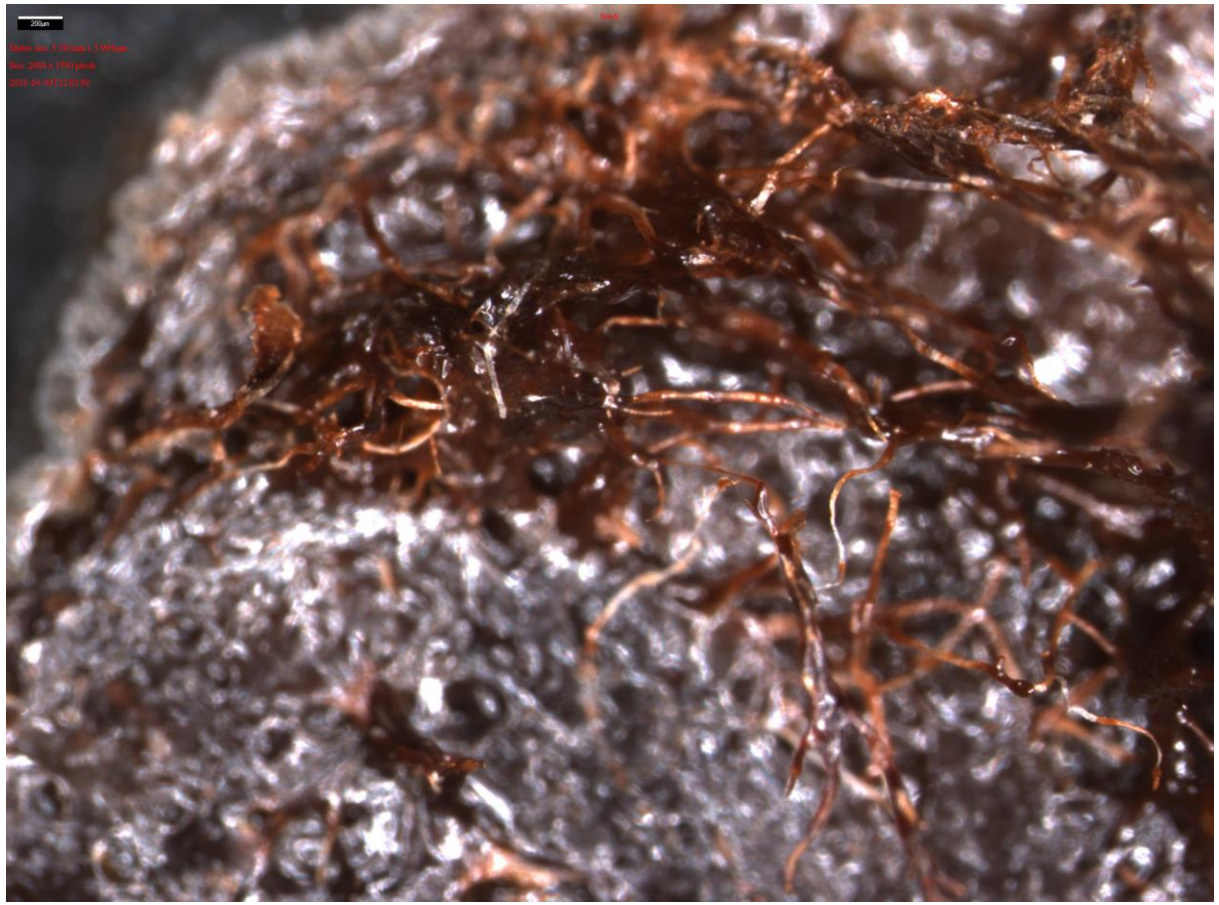


Sample 17	Sample 18	Sample 19	Sample 20
Lignin 40 gr	Lignin 40 gr	Lignin 40 gr	Lignin 60 gr
Cellulose 5 gr	Cellulose 5 gr	Cellulose 5 gr	Cellulose 5 gr
Cellulose 11,1%	Cellulose 11,1%	Cellulose 11,1 %	Cellulose 7,69%
Fluid 27 gr	Fluid 36 gr	Fluid 32 gr	Fluid 38 gr
18,52 /81,5 (h2o/acetone)	27,8/72,2 (h2o/acetone)	31,2/68,8 (h2o/acetone)	26,3/73,7 (h2o/acetone)

- LESS CELLULOSE RESULTED IN BETTER EXTRUSION QUALITY (surface quality)
- AMOUNT OF FLUID DETERMINES STRENGTH (less fluid > higher strength = more extrusion problems)
- CELLULOSE COUNTERACTS BRITTLENESS OF LIGNIN

EXPERIMENTS

MATERIAL SAMPLES



EXPERIMENTS

MATERIAL SAMPLES

EXPERIMENTS

MATERIAL SAMPLES

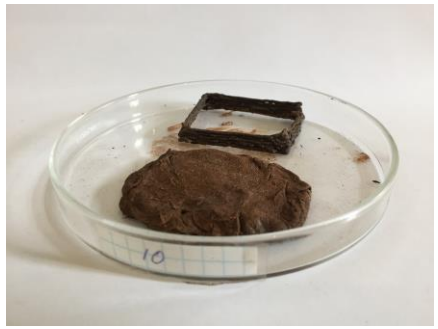
EXPERIMENTS

MATERIAL SAMPLES

MATERIAL SAMPLES FOR PRINTING

Sample 9
Lignin 40 gr
Cellulose 4 gr
Cellulose 9,09 %

Fluid 42 gr
61,9/38,1 (h2o/acetone)



Sample 10
Lignin 40 gr
Cellulose 5 gr
Cellulose 11,1%

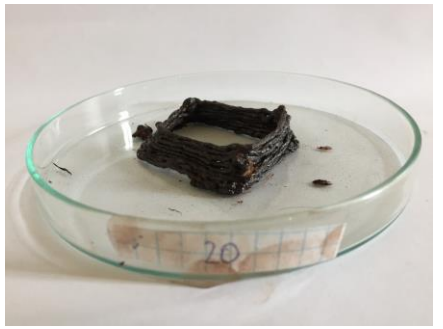
Fluid 46 gr
43,5/56,5 (h2o/acetone)

Sample 11
Lignin 40 gr
Cellulose 10 gr
Cellulose 20%

Fluid 75 gr
60/40 (h2o/acetone)

Sample 16
Lignin 160 gr
Cellulose 12,5 gr
Cellulose 7,25%

Fluid 86 gr
46,5/53,5 (h2o/acetone)

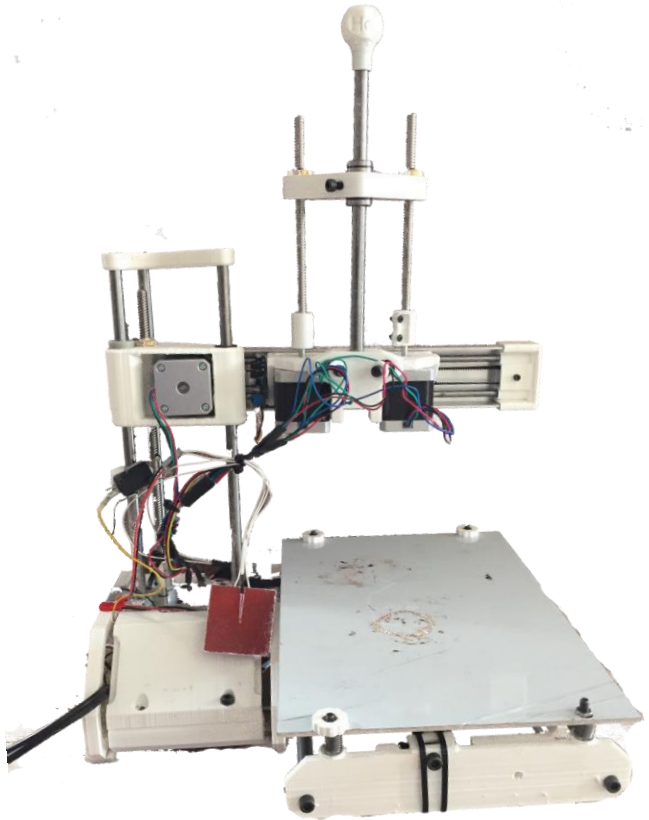


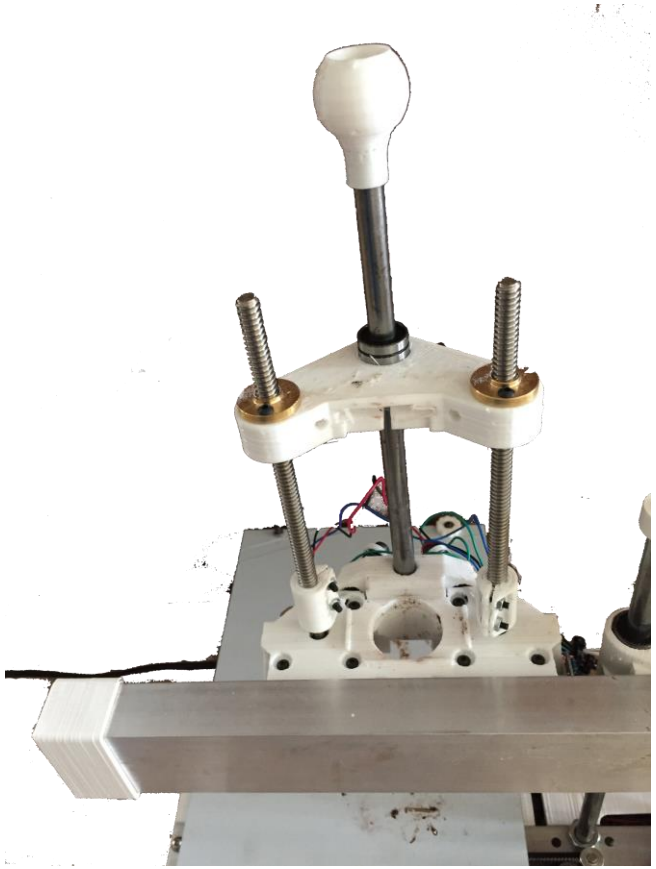
Sample 20
Lignin 60 gr
Cellulose 5 gr
Cellulose 7,69%

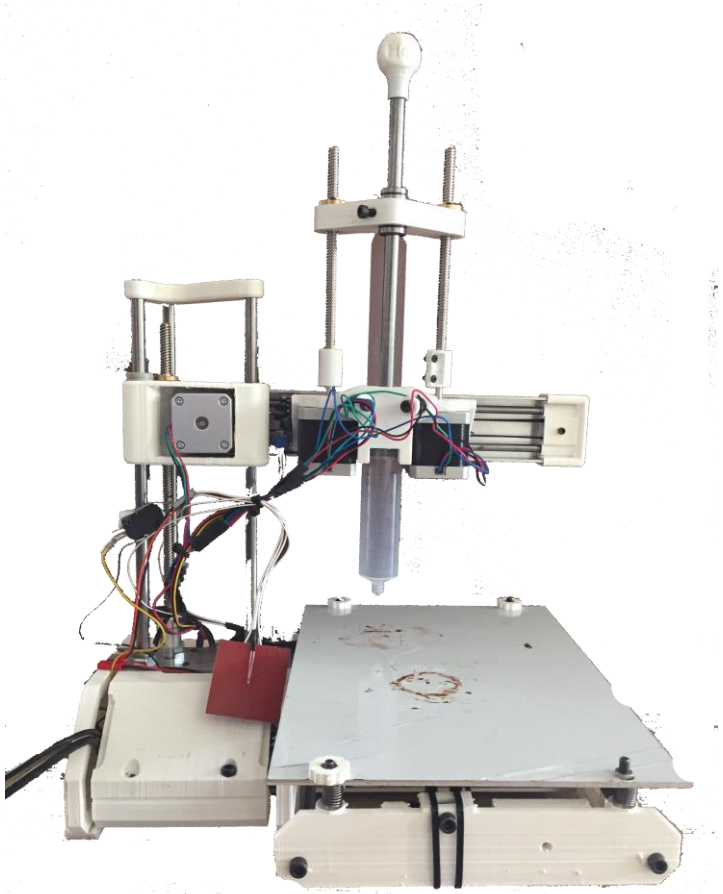
Fluid 38 gr
26,3/73,7 (h2o/acetone)

PROTOTYPE PHASE

PROTOTYPE PHASE





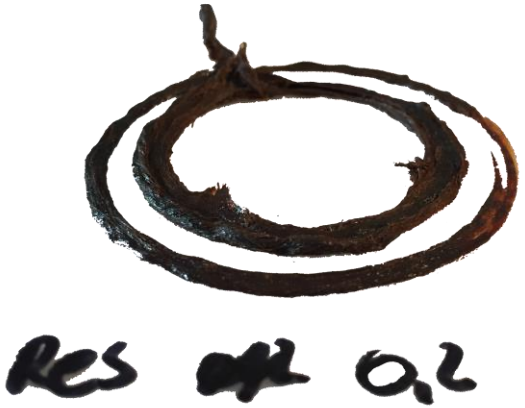


Material
Sample 20
Lignin 60 gr
Cellulose 5 gr
Cellulose 7,69%

Fluid 38 gr
26,3/73,7 (h2o/acetone)

1

Layer height	= 2 mm
Shell thickness	=3 mm
Print speed	=5mm/s
Printing temperature	=0 degrees
Support type	=none
Platform adhesion type	=none
Filament diameter = 29 mm (inner diameter syringe)	
Flow	= 800%
Nozzle size	=1,6 mm



2

Layer height	= 0,2 mm
Shell thickness	=3 mm
Print speed	=5mm/s
Printing temperature	=0 degrees
Support type	=none
Platform adhesion type	=none
Filament diameter = 29 mm (inner diameter syringe)	
Flow	= 200%
Nozzle size	=1,6 mm

3

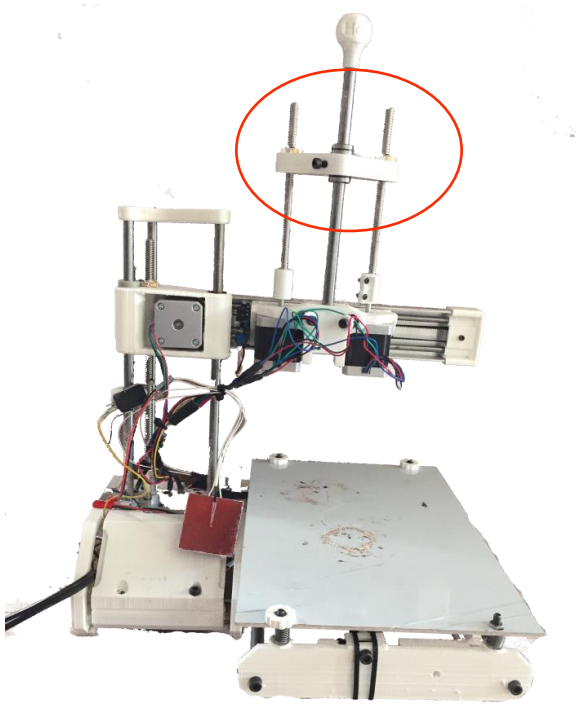
Layer height	= 0,5 mm
Shell thickness	=3 mm
Prints peed	=5mm/s
Printing temperature	=0 degrees
Support type	=none
Platform adhesion type	=none
Filament diameter = 29 mm (inner diameter syringe)	
Flow	= 500%
Nozzle size	=1,6 mm

4

Layer height	= 0,5 mm
Shell thickness	=3 mm
Prints peed	=5mm/s
Printing temperature	=0 degrees
Support type	=none
Platform adhesion type	=none
Filament diameter = 29 mm (inner diameter syringe)	
Flow	= 500%
Nozzle size	=1,6 mm

PROTOTYPE PHASE

PRINTER BROKE DOWN



PRINTER NOT SUITABLE FOR EXTRUDING MATERIAL

MECHANICAL SYSTEM NEEDED TO EXTRUDE THE MATERIAL

THE SOLUTION

APPLICATIONS

APPLICATIONS

WHO WANTS THIS?

APPLICATIONS

WHO WANTS THIS?

WHAT CAN BE DONE WITH THIS?

APPLICATIONS

WILL IT BE USED TO PRINT A TREE?

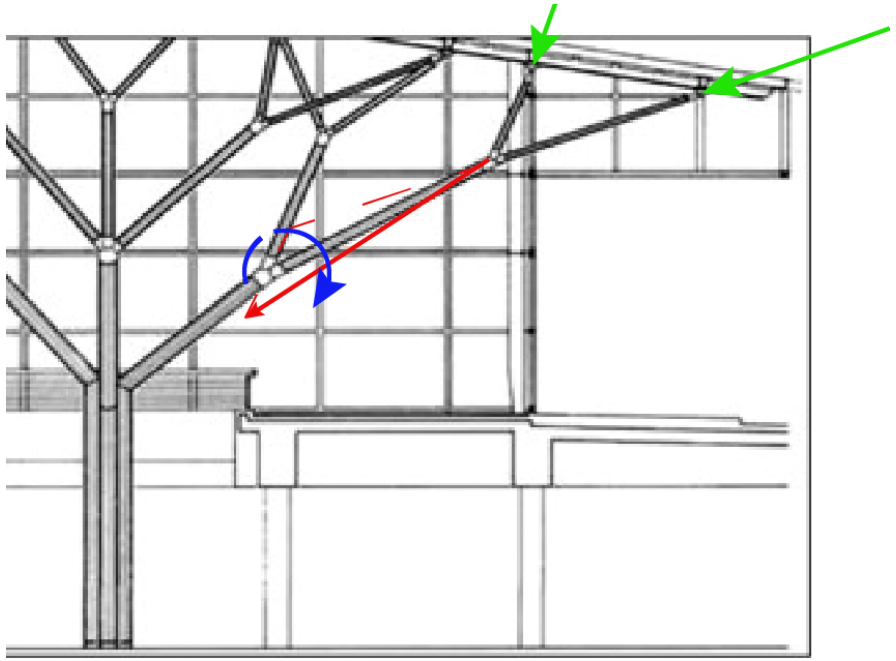
APPLICATIONS

WILL IT BE USED TO PRINT BEAMS?

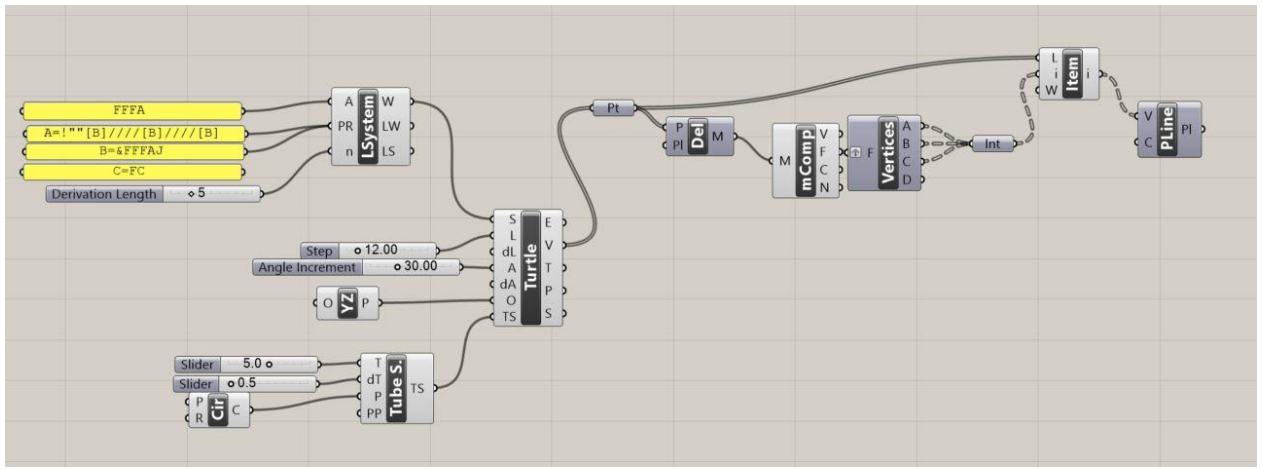
APPLICATIONS

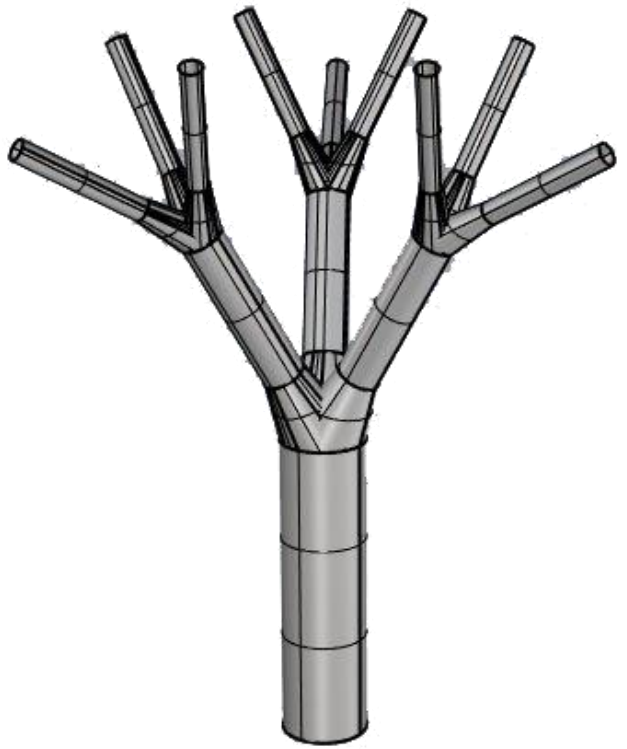
APPLICATIONS

APPLICATIONS

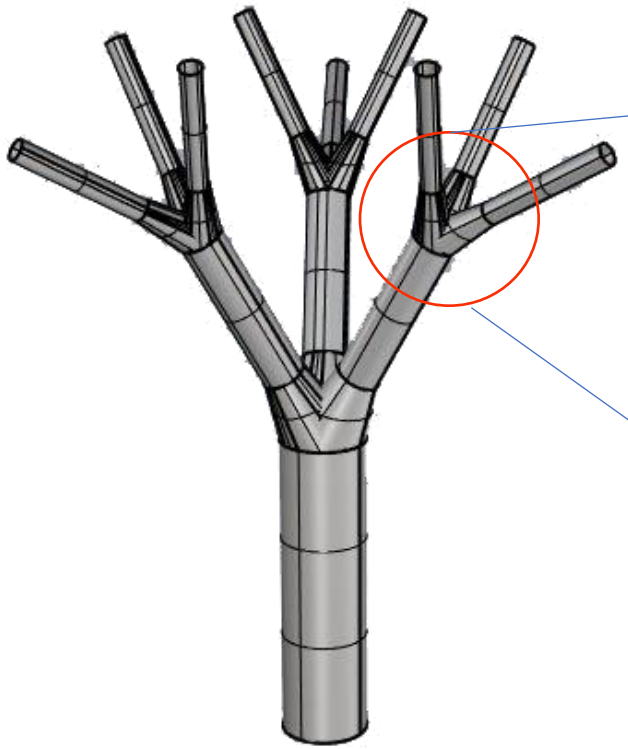


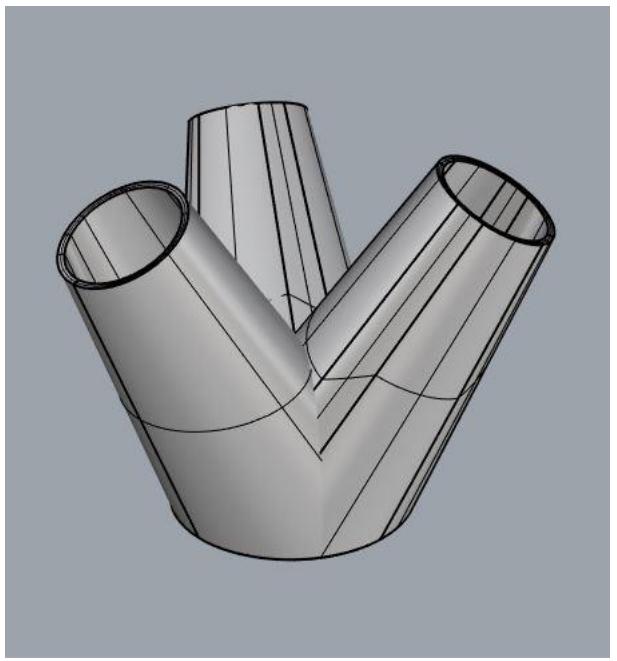
APPLICATIONS



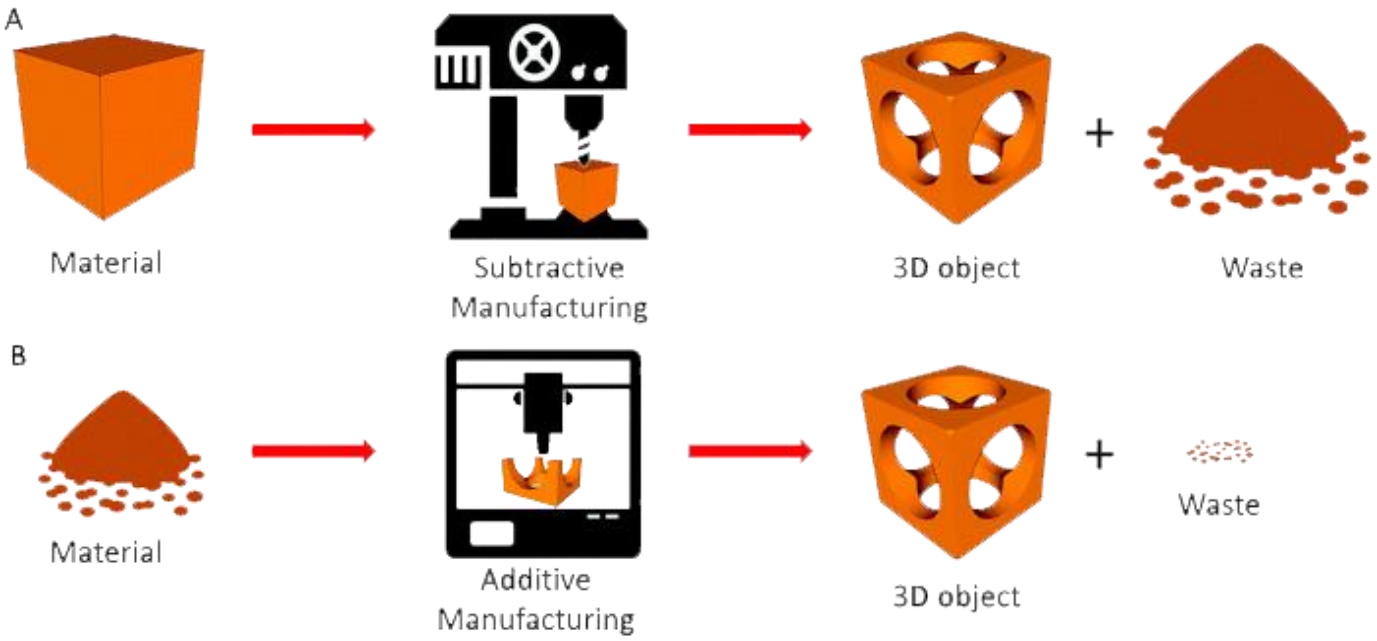


APPLICATIONS

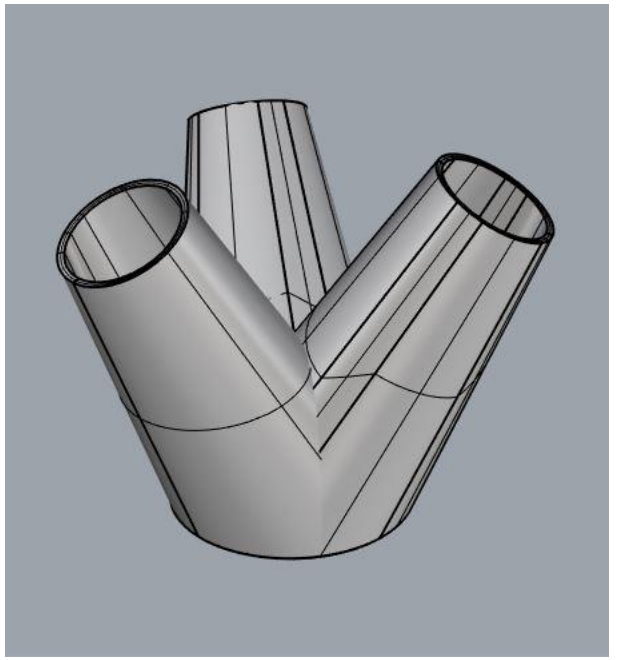




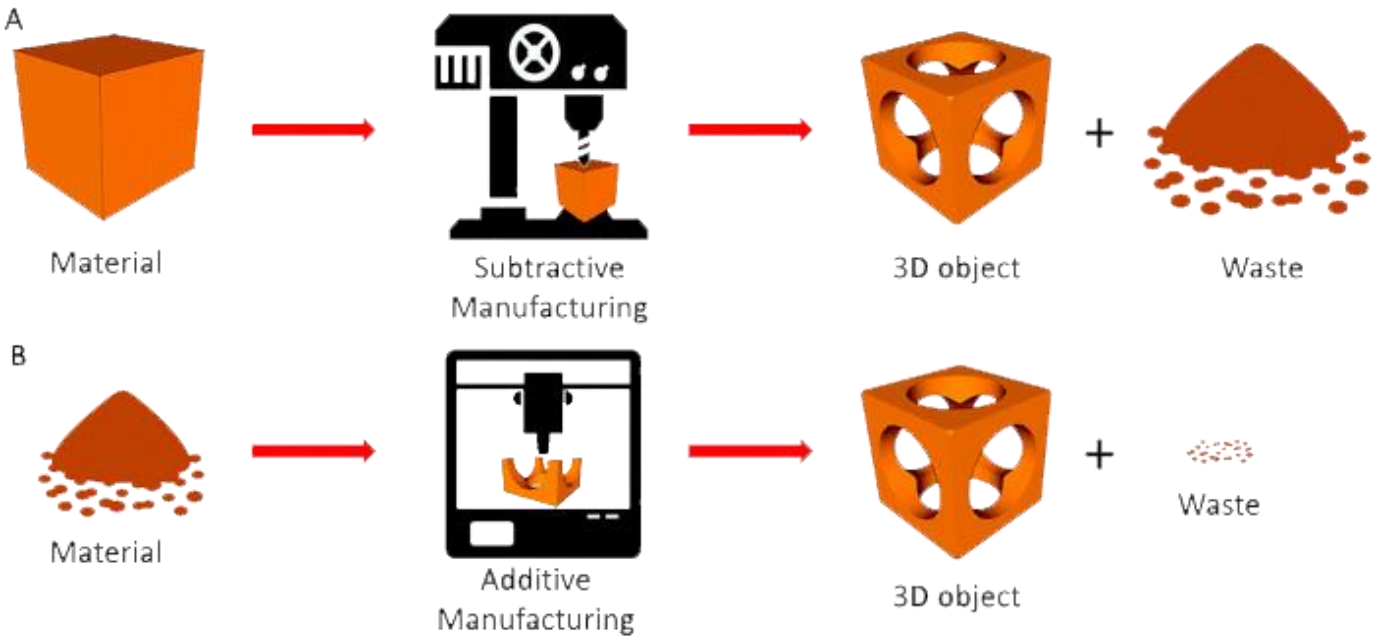
APPLICATIONS



LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL



APPLICATIONS



LESS ASSEMBLY
HIGH CUSTOMIZATION
GEOMETRIC OPTIMIZATION
MATERIAL ECONOMY
RECYCLING POTENTIAL

COMPLEX SHAPED OBJECTS
REPLACEMENT PARTS FOR WINDOWFRAMES
FURNITURE
TOYS

EXTRUDE PANELS
EXTRUDED PROFILES (HOLLOW)

APPLICATIONS

CONCLUSION

CONCLUSION

CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?

CONCLUSION

BACKGROUND QUESTIONS

WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?

HOW CAN THE COMPONENTS OF WOOD BE COMBINED IN A PRINTABLE MATERIAL?

CONCLUSION

BACKGROUND QUESTIONS

WHAT IS WOOD AND WHAT ARE THE PROPERTIES OF WOOD AND ITS COMPONENTS?

CONCLUSION

CAN WOOD BE USED IN AN ADDITIVE MANUFACTURING PROCESS?

RESOURCES OF RAW MATERIAL
MORE TESTS NEEDED WITH 3D PRINTER
MORE TESTS WITH DIFFERENT PRINT PARAMETERS
STRENGTH OF MATERIAL SHOULD TESTED
DIFFERENT FIBER LENGTHS SHOULD BE TESTED
MORE RESEARCH IS NEEDED ON THE ESTHETICS OF THE MATERIAL

THANK YOU