

CONCRETE

in an AM process

Freeform concrete processing

Dennis de Witte

P5 presentation

30 January 2015 16:00

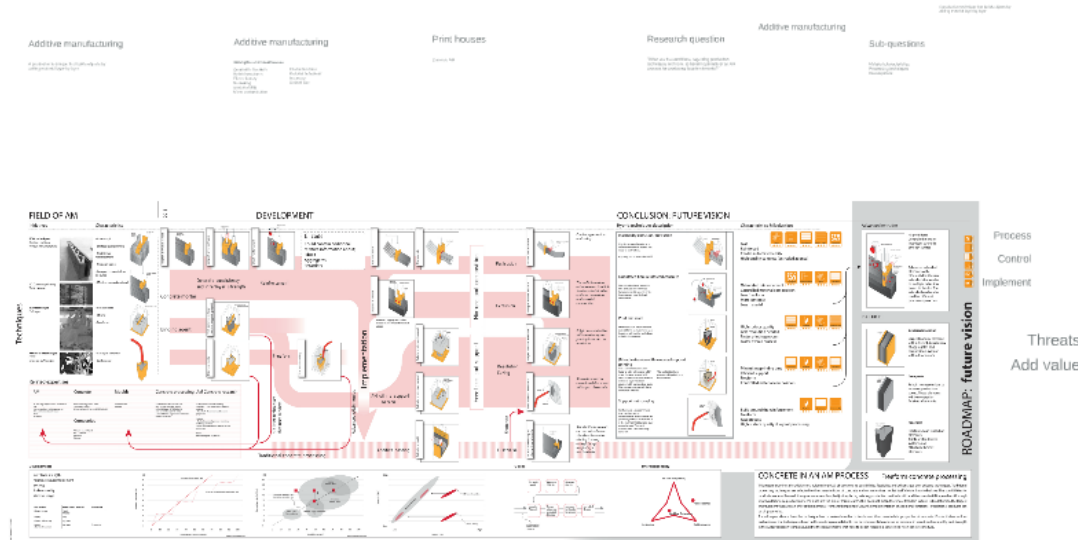
CONCRETE

in an AM process

Freeform concrete processing

- Introduction
- Research
- AM of concrete
- Roadmap
- Conclusions & recommendation

- Inter layer strength
- Reinforcement
- Material composition
- Anisotropy
- Process



Additive manufacturing

A production technique that builds objects by adding material layer by layer

Additive manufacturing

Strengths and weaknesses

Geometric freedom

Hybrid structures

File to factory

No tooling

Sustainability

Mass customisation

Production time

Material behaviour

Accuracy

Limited size

Print houses

Concrete AM

Research question

"What are the conditions, regarding production techniques and form, to benefit optimally of an AM process for producing façade elements?"

Sub-questions

Material characteristics
Processing techniques
Development

FIELD OF AM

2015

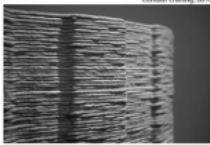
DEVELOPMENT

Initiatives

FDM technique
Contour crafting
Winsun new materials



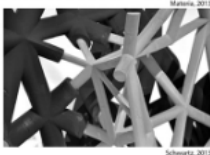
3D Concrete printing
Total custom



3DP technique
D-Shape

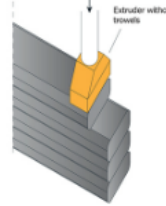
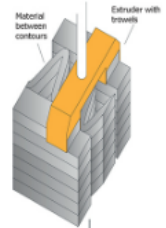


AM mould technique
EZCT
(moulds by Voxjet)

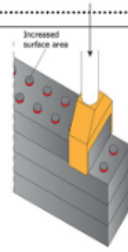


Characteristics

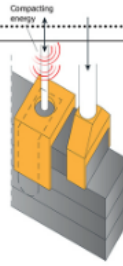
- Anisotropic
- Surface quality differs
- No internal reinforcement
- No aggregates
- Compact concrete low air bulbs
- Missing support material
- Not concrete
- Strong
- Freeform
- Isotropic concrete
- Lost mould



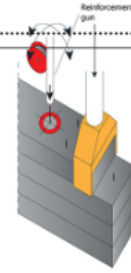
Roughen extruded surface



Compact after extrusion



Shoot reinforcement



G-code

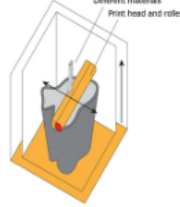
Could contain additional mixture information about:
Fibres
Aggregates
Retarders

Concrete consistency and interlayer strength

Reinforcement

Concrete mortar

Print concrete without complete support (polyjet)



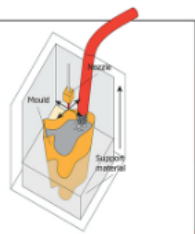
Binding agent

Print eco mould



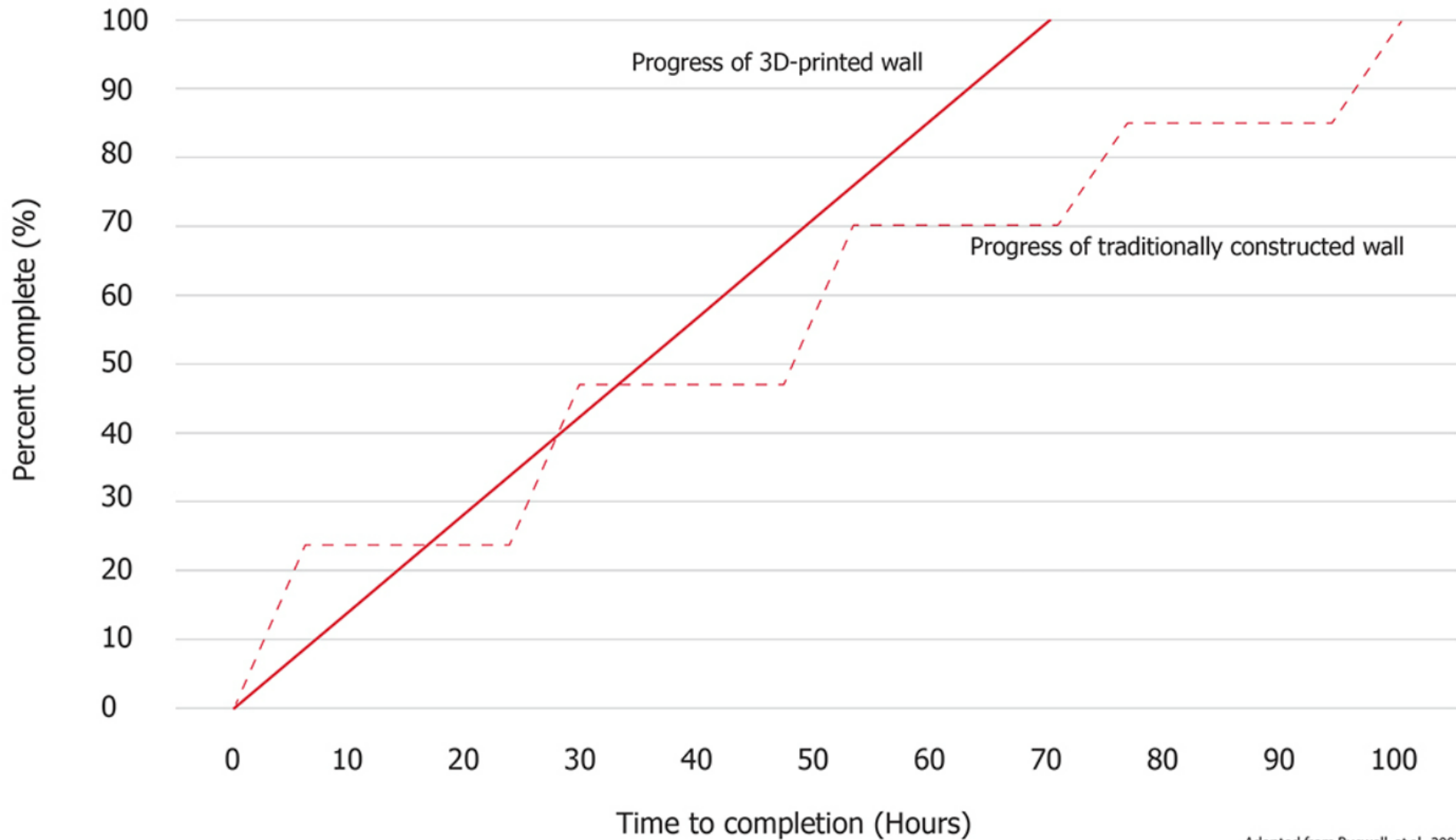
Freeform

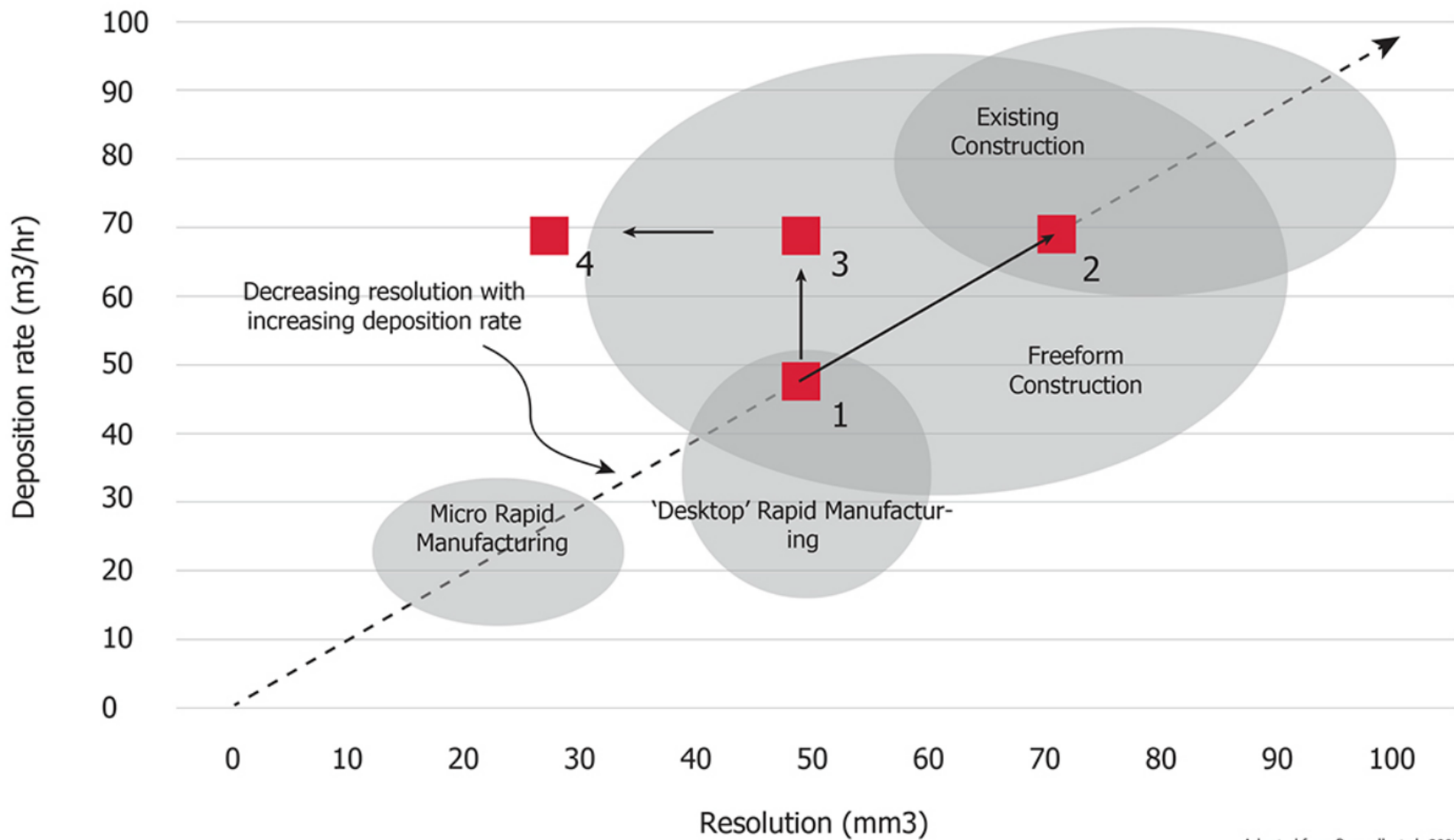
Thin mould casting

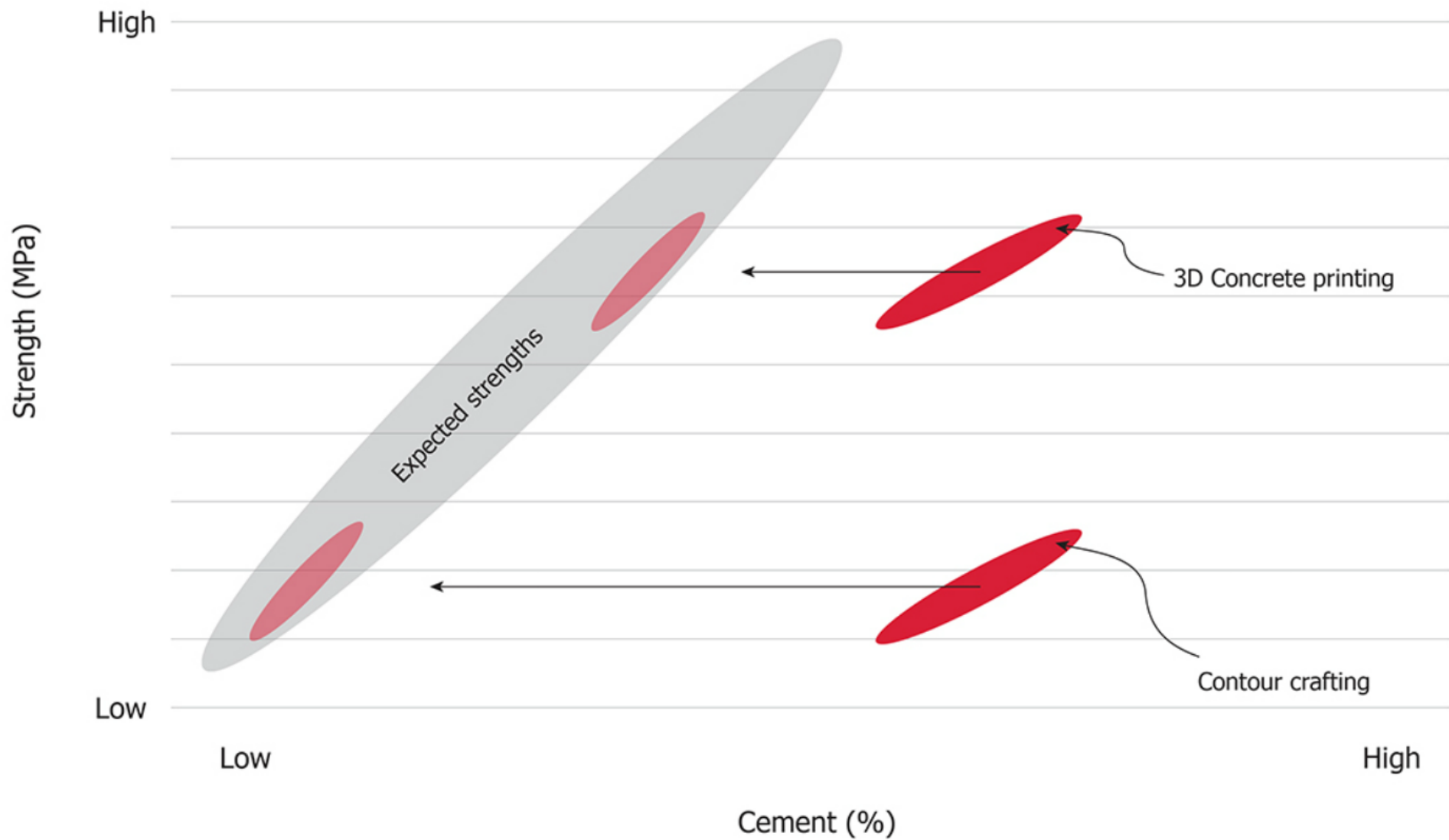


Related expertises

Mechanism	Constituent material	Composite
Phase change	Steel Plastics	
Drying	Clay	
Chemical bonding	Gypsum	
Instant chemical reaction	Cement	Concrete

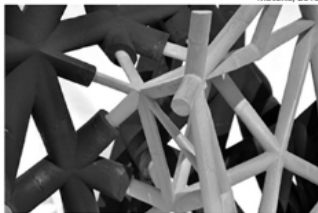








Materia, 2013



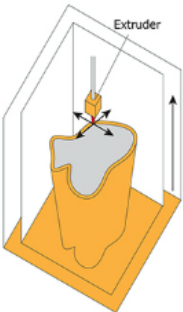
Schwartz, 2013

AM mould technique EZCT (moulds by Voxeljet)

- Isotropic concrete
- Lost mould



Print eco mould



Related expertises

AM

- Dr. Dipl.-Ing. Holger Strauss (Hochschule OWL)
- Erno Langenberg (printing ceramic)
- DUS Architecten (Canel House)
- MX3D
- NSTRMNT

Concrete

- Werner Sobek gradient beton
- Stuttgart University
- Mw. dr. ir. S.A.A.M. Fennis (CiTG TU-Delft)

Moulds

- ir. Siebe Bakker
- Voxeljet

Concrete processing AM Concrete research

- Sascha Hickert (Hochschule OWL)
- Prof. Dipl.Ing. Matthias Michel
- ir. Roel Schipper (CiTG TU-Delft)
- dr.ir. Karel Vollers (BK TU-Delft)
- Adapa (DK) MSc Eng Thomas Henriksen
- Rieder Group (AT)

- TU Eindhoven concrete printing
- prof.dr.ir. T.A.M. (Theo) Salet - support material
- Rob Wolfs - Parameters and concrete properties

Companies

- Winsum new materials
- EZCT / Voxeljet
- BetaBram
- Skanska

- TU Delft
- Evaluating techniques and searching matching products
- Experiments with new concepts for AM of concrete

- Saxion
- Breakthrough in 3D printing



Inter layer strength

Reinforcement

Material composition

Anisotropy

Process

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Techniques

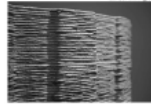
Initiatives

FDM technique
Contour crafting
Winsun new materials



- Anisotropic
- Surface quality differs
- No internal reinforcement
- No aggregates
- Compact concrete low air bulbs

3D Concrete printing
Total custom



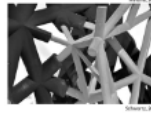
- Missing support material

3DP technique
D-Shape



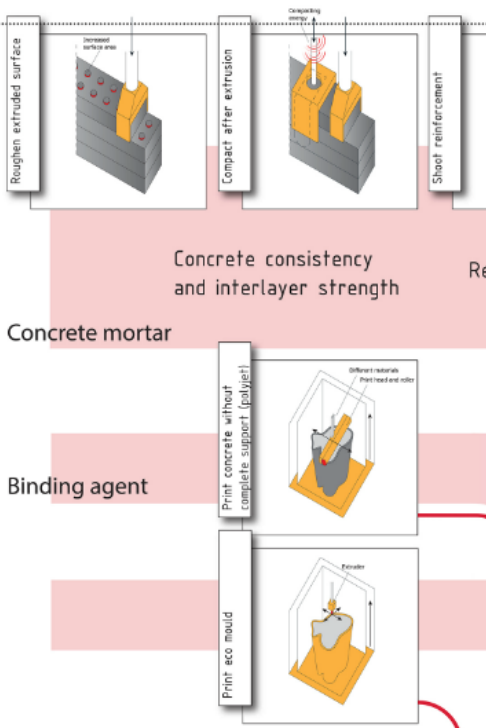
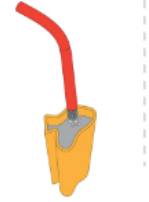
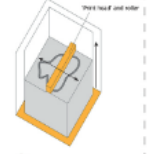
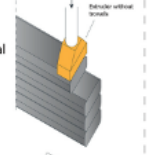
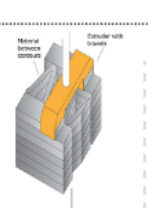
- Not concrete
- Strong
- Freeform

AM mould technique
EZCT
(moulds by Voxjet)



- Isotropic concrete
- Lost mould

Characteristics



Related expertises

AM	Concrete	Moulds	Concrete processing	AM Concrete research
Dr. Dipl.-Ing. Holger Strauss (Hochschule OWL) Erno Langenberg (printing ceramic) GUS Architects (Canel House) MKSD NSTRANT	Werner Sobek gradient beton Stuttgart University Mw. dr. ir. S.A.A.M. Fennis (CI/TU-Delft)	ir. Siebe Bakker Voxjet	Saicha Hickert (Hochschule OWL) Prof. Dipl.-Ing. Matthias Michael ir. Rüdiger Schöpfer (CI/TU-Delft) dr. ir. Karel Volkers (TU Delft) Adapa (DK) MSc Eng Thomas Henriksen Riedel Group (AT)	TU Eindhoven concrete printing - prof.dr. ir. T.A.M. (Theo) Savelier - support materials - Rob Wolfs - Parameters and concrete properties TU Delft - Evaluating techniques and searching matching products - Experiments with new concepts for AM of concrete Saxion Breakthrough-in 3D printing
	Companies Winsun new materials EZCT / Voxjet Beulaborn Skanska			

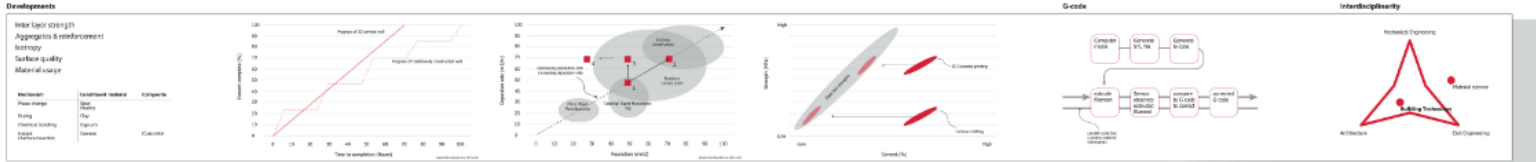
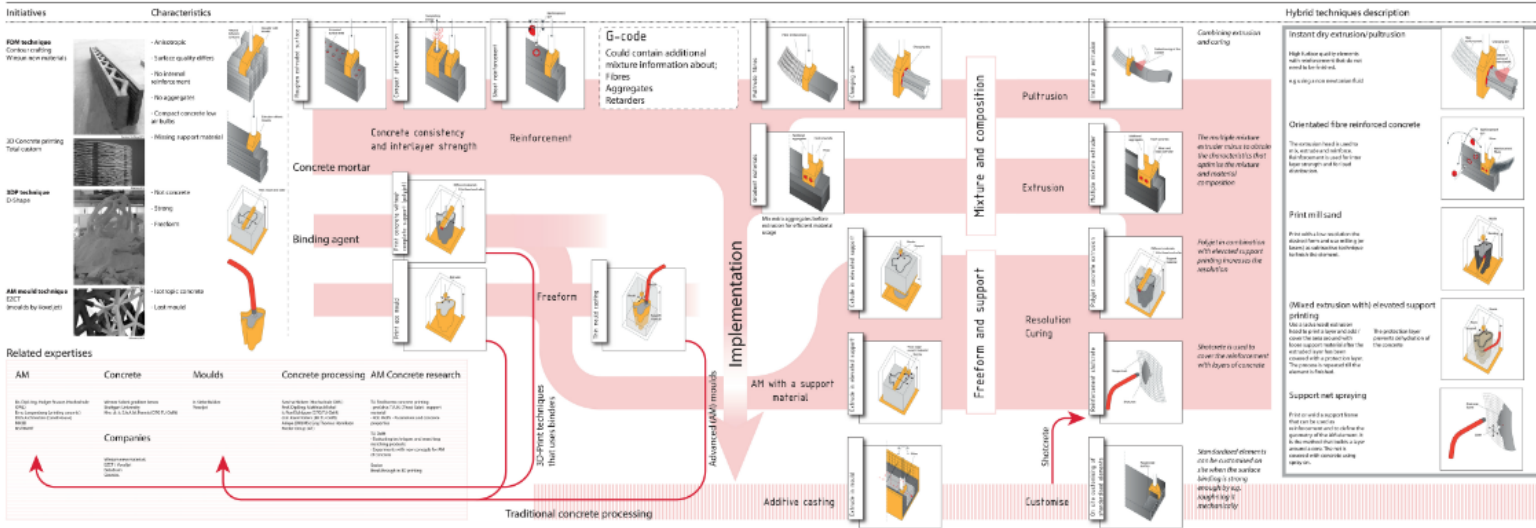
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DEVELOPMENT

CONCLUSION: FUTURE VISION



Characteristics & Evaluation

- Fast Reinforced
- Can be automated easily
- High quality concrete (printed at once)
- Orientated reinforcement
- Controlled material composition
- Less free form
- More isotropic
- Less material
- High surface quality
- Less resolution needed
- Factor printing process
- Factor overall process
- Minimising printing time
- Efficient support
- Freeform
- Controlled material composition
- Build around the reinforcement
- Freeform
- Fast process
- High surface quality due post processing

Advanced extruder

- Align fibres
- Control and orient layer layer strength
- Smooth surface
- Advanced extruded elements with different densities are extruded at once due to multiple extrusion points in the die. The extruder head can be used for different process approaches.

PRODUCTS

- Gradient material**: Large structural elements as full dense distribution of aggregates and composites (IMC) or without Reinforcement.
- Core parts**: Print in low resolution, to integrate production speed. These elements will be covered or filled afterwards.
- Freeform**: Problems, high resolution elements, dense of elements, systems, and 3D reinforcement elements.

CONCRETE IN AN AM PROCESS

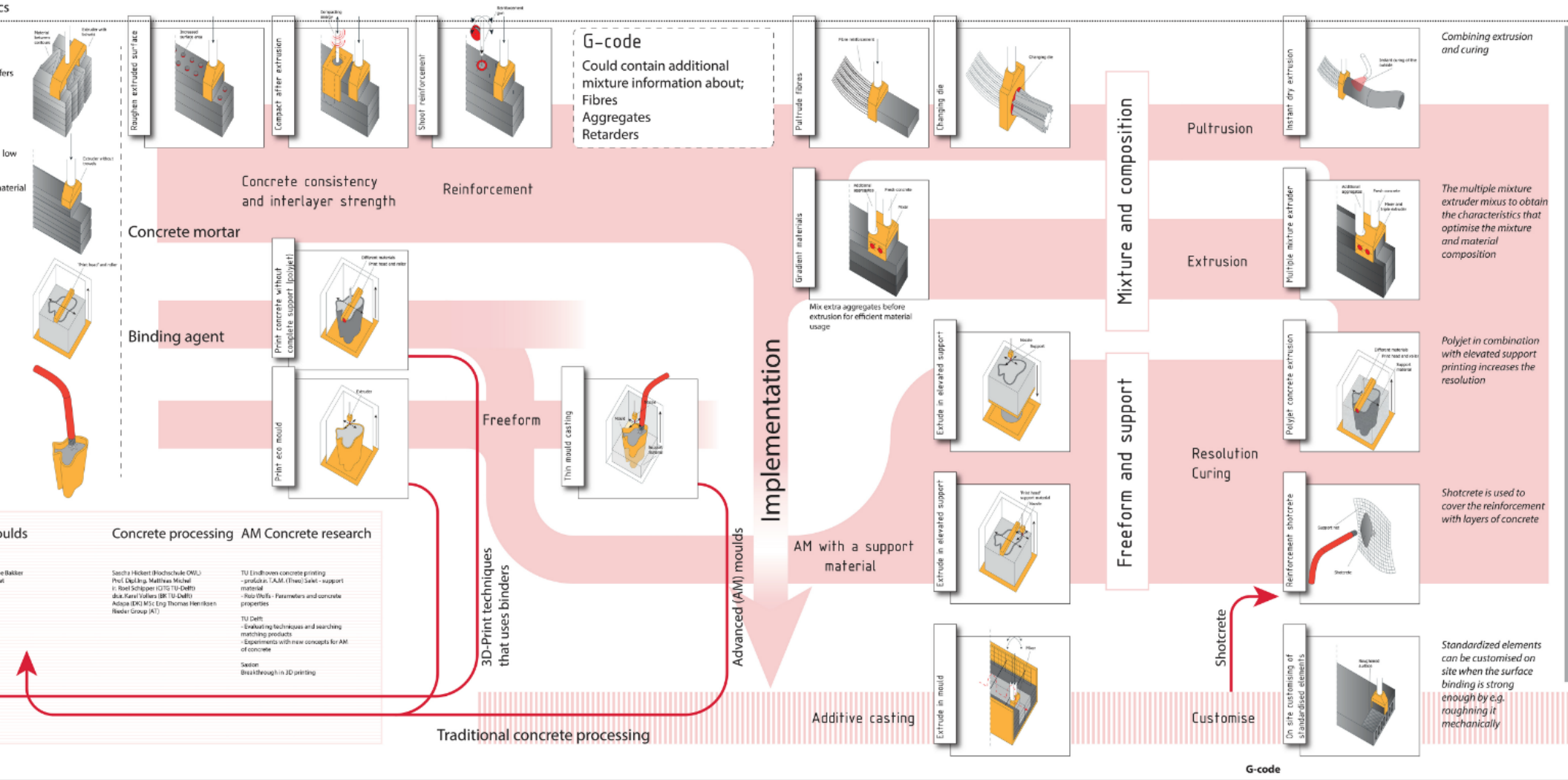
Freeform concrete processing

This report examines the additive manufacturing (AM) of concrete, its possibilities, feasibility and advantages over existing techniques. Traditional processing techniques are adapted to the characteristics of concrete and concrete does not lend itself to 3D printing. The possibilities for products made with an additive process are endless, but not existing printing production methods with additive are still impossible. Although improved freeform production techniques are the aim of this research, this does not mean that more freedom in form is by definition the largest improvement that AM can offer at the moment. From another point of view the implementation of additional functions in traditional products can lead to great value.

A roadmap outlines how the technique has to evolve to implement the characteristic properties of concrete. Product ideas and an evaluation of the techniques shown in the roadmap are related to the developments to achieve an increase in speed, surface quality and strength in the AM production techniques, next to the requirements that have to be set regarding a building level concrete structure.

ROADMAP: future vision

DEVELOPMENT



G-code
 Could contain additional mixture information about;
 Fibres
 Aggregates
 Retarders

Concrete consistency and interlayer strength

Reinforcement

Mixture and composition

Freeform and support

Implementation

AM with a support material

3D-Print techniques that uses binders

Advanced (AM) moulds

Traditional concrete processing

Additive casting

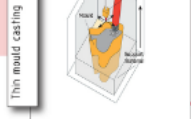
Customise

G-code

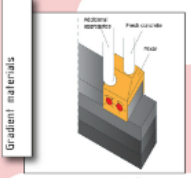
Concrete processing AM Concrete research

- Sacha Hickert (Hochschule OWL)
 - Prof. Dr.-Ing. Matthias Michel
 - Prof. Dr. Rolf Schöpfer (GTG TU-Delft)
 - Prof. Dr. Kai-Ingo Voigt (IKT TU-Delft)
 - Adapa (DKG) MS Eng. Thomas Henriksen
 - Reader Group (AT)
- TU Eindhoven concrete printing
 - prof.dr. TAM. (Thao) Salet - support material
 - Rico Wrolo - Parameters and concrete properties
- TU Delft
 - Evaluating techniques and searching matching products
 - Experiments with new concepts for AM of concrete
- Svecon
 - Breakthrough in 3D printing

Freeform

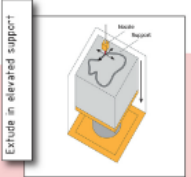


Thin mould casting

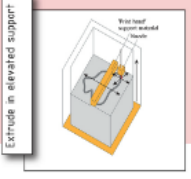


Gradient materials

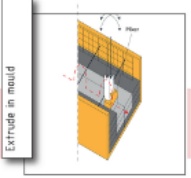
Mix extra aggregates before extrusion for efficient material usage



Extrude in elevated support

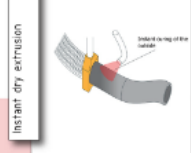


Extrude in elevated support



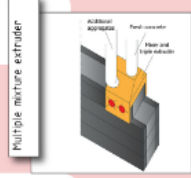
Extrude in mould

Pultrusion



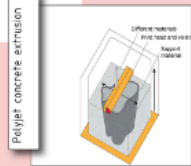
Instant dry extrusion

Extrusion



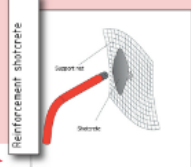
Multiple mixture extruder

Resolution Curing



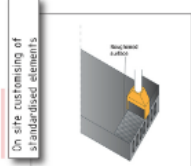
Polyjet concrete extrusion

Reinforcement shotcrete



Reinforcement shotcrete

Standardized elements



On site customising of standardized elements

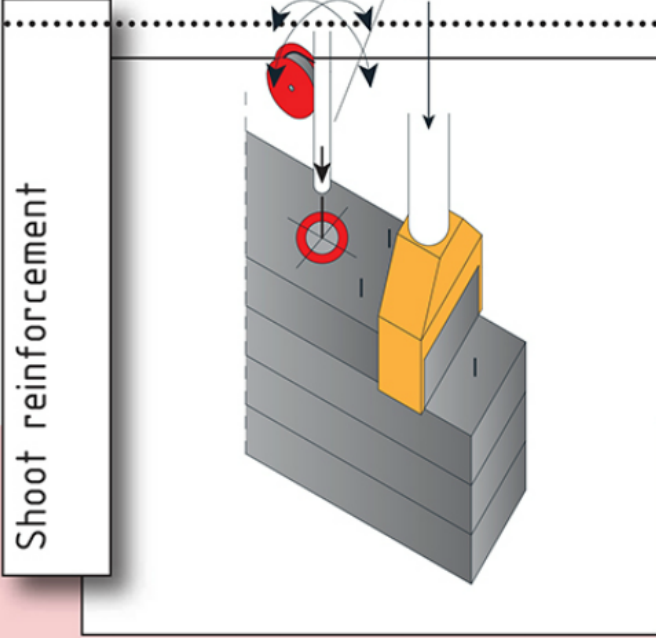
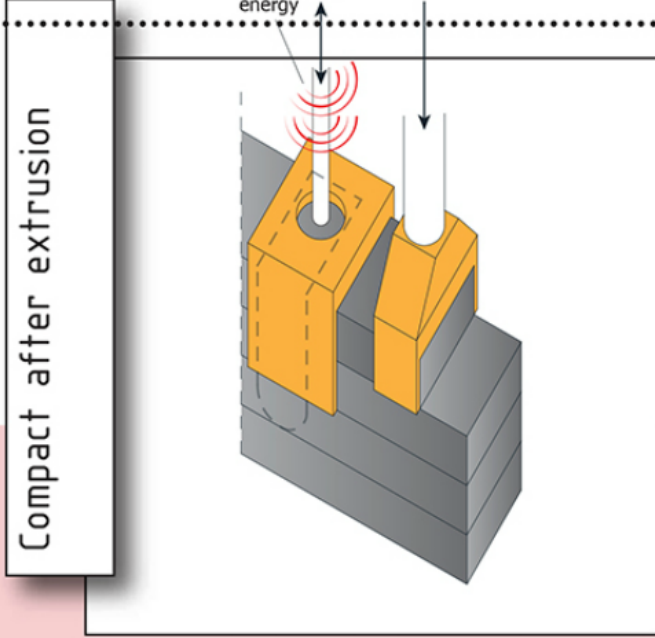
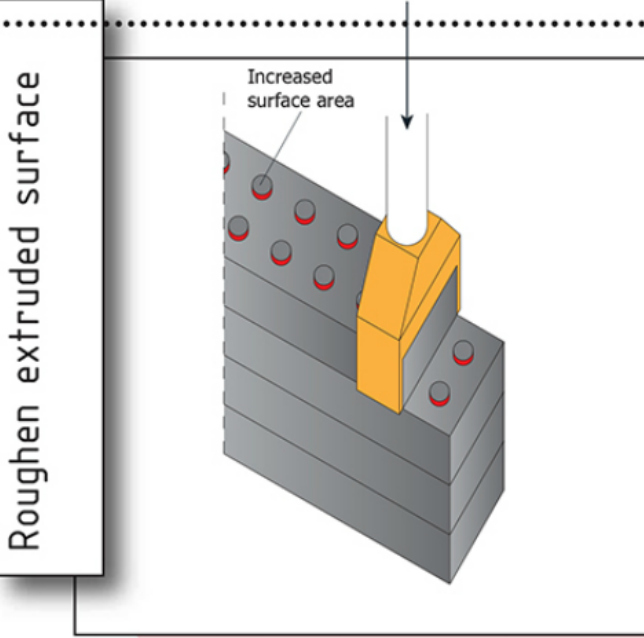
Combining extrusion and curing

The multiple mixture extruder mixers to obtain the characteristics that optimise the mixture and material composition

Polyjet in combination with elevated support printing increases the resolution

Shotcrete is used to cover the reinforcement with layers of concrete

Standardized elements can be customised on site when the surface binding is strong enough by e.g. roughing it mechanically



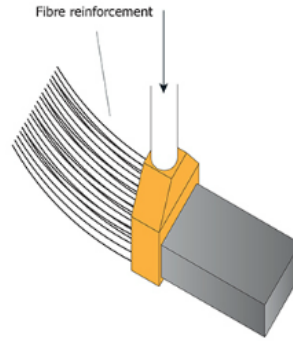
Concrete consistency and interlayer strength

Reinforcement

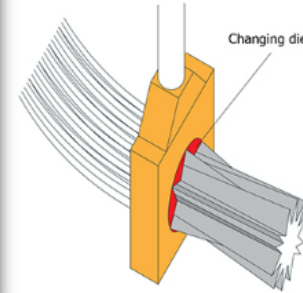
G-code

Could contain additional mixture information about;
Fibres
Aggregates
Retarders

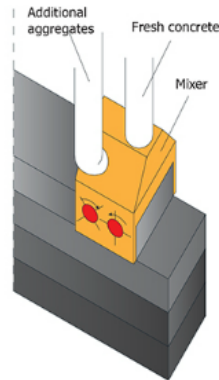
Pultrude fibres



Changing die



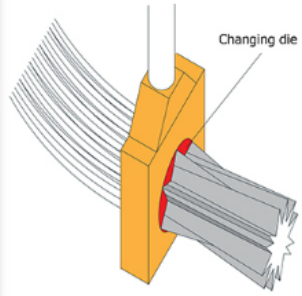
Gradient materials



Mix extra aggregates before extrusion for efficient material usage

Mixture and composition

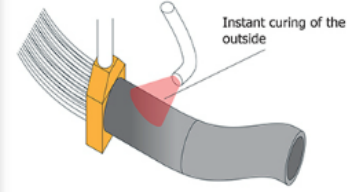
Changing die



Mixture and composition

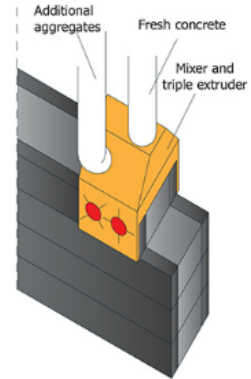
Pultrusion

Instant dry extrusion



Combining extrusion and curing

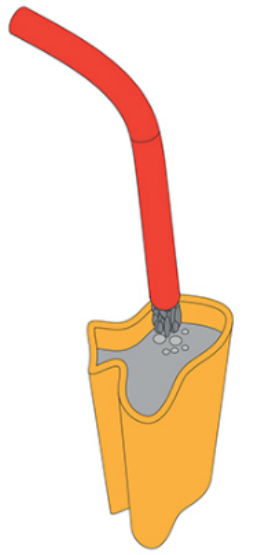
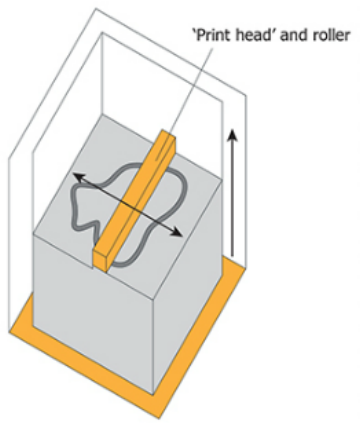
Multiple mixture extruder



Extrusion

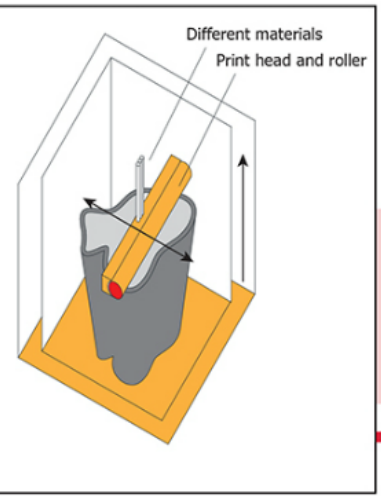
The multiple mixture extruder mixus to obtain the characteristics that optimise the mixture and material composition

Concrete mortar

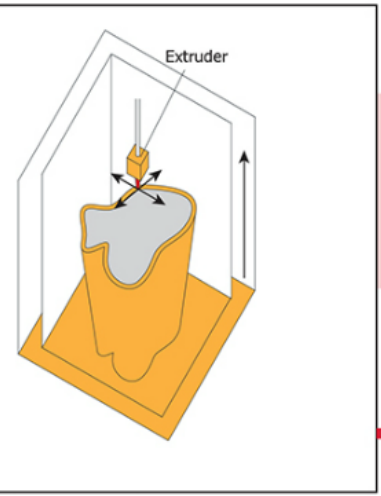


Binding agent

Print concrete without complete support (polyjet)

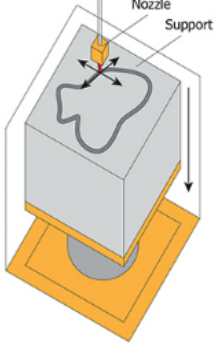


Print eco mould

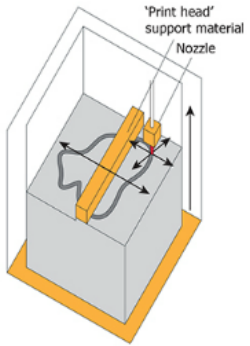


Free

Extrude in elevated support



Extrude in elevated support

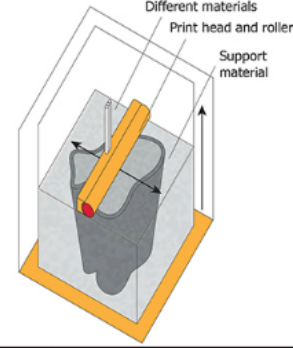


Mixt

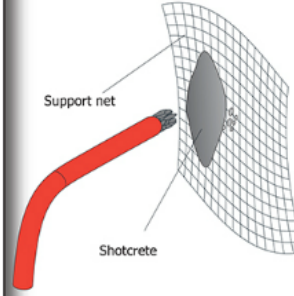
Freeform and support

Resolution
Curing

Polyjet concrete extrusion



Reinforcement shotcrete

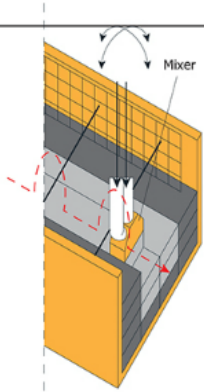


Polyjet in combination with elevated support printing increases the resolution

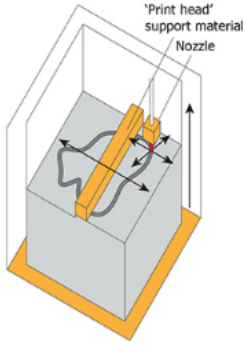
Shotcrete is used to cover the reinforcement with layers of concrete

ete

Extrude in mould



Extrude in elevated support



Extrude



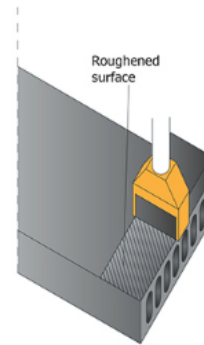
Freeform and sup

Customise

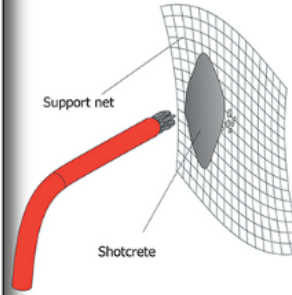
Shotcrete

Resolution
Curing

On site customising of
standardised elements



Reinforcement shotcrete



Polyje



*Standardized elements
can be customised on
site when the surface
binding is strong
enough by e.g.
roughning it
mechanically*

*Shotcrete is used to
cover the reinforcement
with layers of concrete*

FIELD OF AM

Initiatives

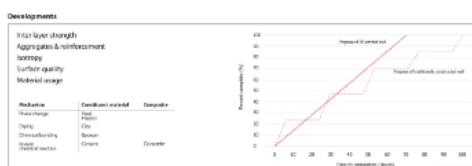
- Fibertechnique**
Controlled casting
Without new materials
- 3D printing**
Full color
- 3D printing**
3D pipe
- AM mold technique**
CNC (molds by 3Dprint)

Characteristics

- Aerotropic
- Surface quality differs
- No internal reinforcement
- No aggregates
- Compact concrete flow
- Missing support material
- Not concrete
- Strong
- Freeform
- Isotropic concrete
- Lost material

Related experts

AM	Concrete	Moulds	Concrete processing	AM Concrete research
<ul style="list-style-type: none"> Support: High-resolution/low-cost Material: High-resolution/low-cost Process: High-resolution/low-cost 	<ul style="list-style-type: none"> Material: High-resolution/low-cost Process: High-resolution/low-cost 	<ul style="list-style-type: none"> Material: High-resolution/low-cost Process: High-resolution/low-cost 	<ul style="list-style-type: none"> Material: High-resolution/low-cost Process: High-resolution/low-cost 	<ul style="list-style-type: none"> Material: High-resolution/low-cost Process: High-resolution/low-cost
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DEVELOPMENT

Concrete consistency and interlayer strength

Reinforcement

Concrete mortar

Binding agent

Freeform

Implementation

AM with a support material

Additive casting

Freeform and support

Mixture and composition

Pultrusion

Extrusion

Resolution

Curing

Shootecrete

Customise

G-code

Concrete's extrusion and curing

Hybrid techniques description

Instant dry extrusion (pultrusion)

Orientated fibre reinforced concrete

Pultrusion

Extrusion

Resolution

Curing

Shootecrete

Customise

G-code

Concrete's extrusion and curing

Hybrid techniques description

Instant dry extrusion (pultrusion)

Orientated fibre reinforced concrete

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CONCLUSION: FUTURE VISION

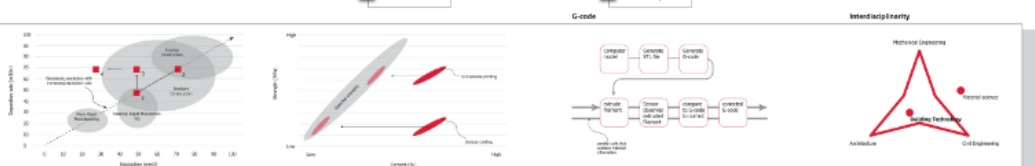
Characteristics & Evaluation

- Fast Reinforced
- Can be automated easily
- High quality concrete (retracted at once)
- Orientated reinforcement
- Controlled material composition
- Less free form
- More isotropic
- Less material
- High surface quality
- Less resolution needed
- Fast printing process
- Faster overall process
- Minimizing printing time
- Efficient support
- Freeform
- Controlled material composition
- Build around the reinforcement
- Freeform
- Fast process
- High surface quality due post processing

Advanced extruder

- Aligned fibers
- Controlled retractive layer strength
- Smooth surface
- Advanced extruded elements with different densities are extruded at once due to multiple extrusion points in the die. The extruder head can be used for different process applications.
- Gradient material
- Large structural elements with different distribution of aggregates and composition, DDM or without network.
- Cure parts
- Print in low resolution, to integrate production speed. These elements will be covered or finished afterwards.
- Freeform
- Freeform, high-resolution elements.
- Layers of standard systems, and 3D reinforcement elements.

ROADMAP: future vision



CONCLUSION: FUTURE VISION

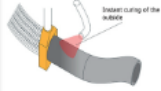
Hybrid techniques description

Characteristics & Evaluation

Mixture and composition

Pultrusion

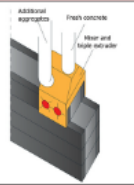
Instant dry extrusion



Combining extrusion and curing

Extrusion

Multiple mixture extruder

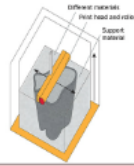


The multiple mixture extruder mixes to obtain the characteristics that optimise the mixture and material composition

Freeform and support

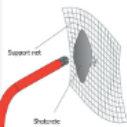
Resolution Curing

Polyjet concrete extrusion



Polyjet in combination with elevated support printing increases the resolution

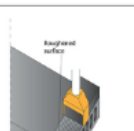
Reinforcement shotcrete



Shotcrete is used to cover the reinforcement with layers of concrete

Shotcrete

Customising of standardised elements

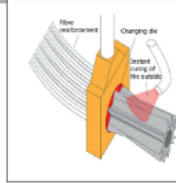


Standardized elements can be customised on site when the surface binding is strong enough by e.g. roughening it

Instant dry extrusion/pultrusion

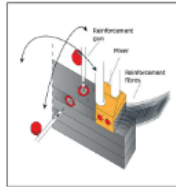
High surface quality elements with reinforcement that do not need to be finished.

e.g. using a non newtonian fluid



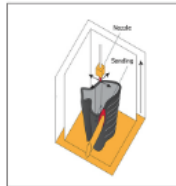
Orientated fibre reinforced concrete

The extrusion head is used to mix, extrude and reinforce. Reinforcement is used for inter layer strength and for load distribution.



Print mill sand

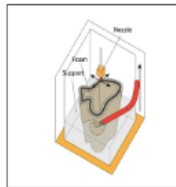
Print with a low resolution the desired form and use milling (or lasers) as subtractive technique to finish the element.



(Mixed extrusion with) elevated support printing

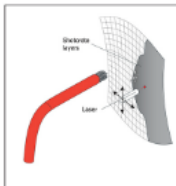
Use a (advanced) extrusion head to print a layer and add / cover the area around with loose support material after the extruded layer has been covered with a protection layer. The process is repeated till the element is finished.

The protection layer prevents dehydration of the concrete



Support net spraying

Print or weld a support frame that can be used as reinforcement and to define the geometry of the AM element. It is the method that builds a layer around a core. The net is covered with concrete using spray on.



Fast Reinforced
Can be automated easily
High quality concrete (extruded at once)



Orientated reinforcement
Controlled material composition
Less free form
More isotropic
Less material



High surface quality
Less resolution needed
Faster printing process
Faster overall process



Minimising printing time
Efficient support
Freeform
Controlled material composition

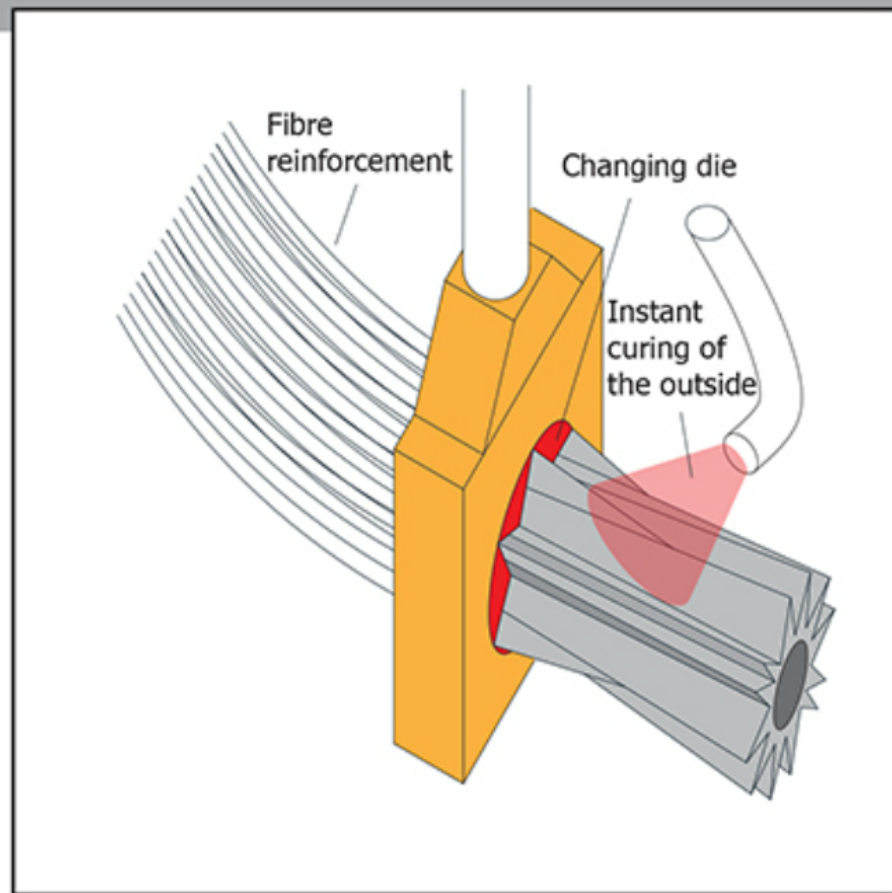


Build around the reinforcement
Freeform
Fast process
High surface quality due post processing

cription

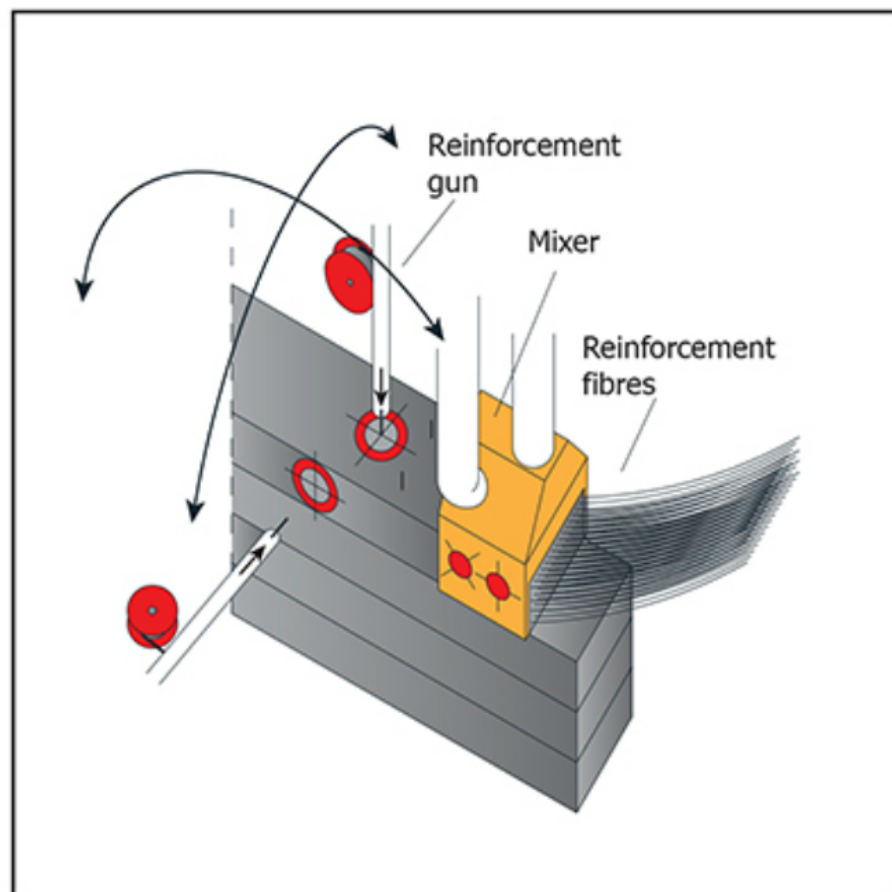
Char

Intrusion

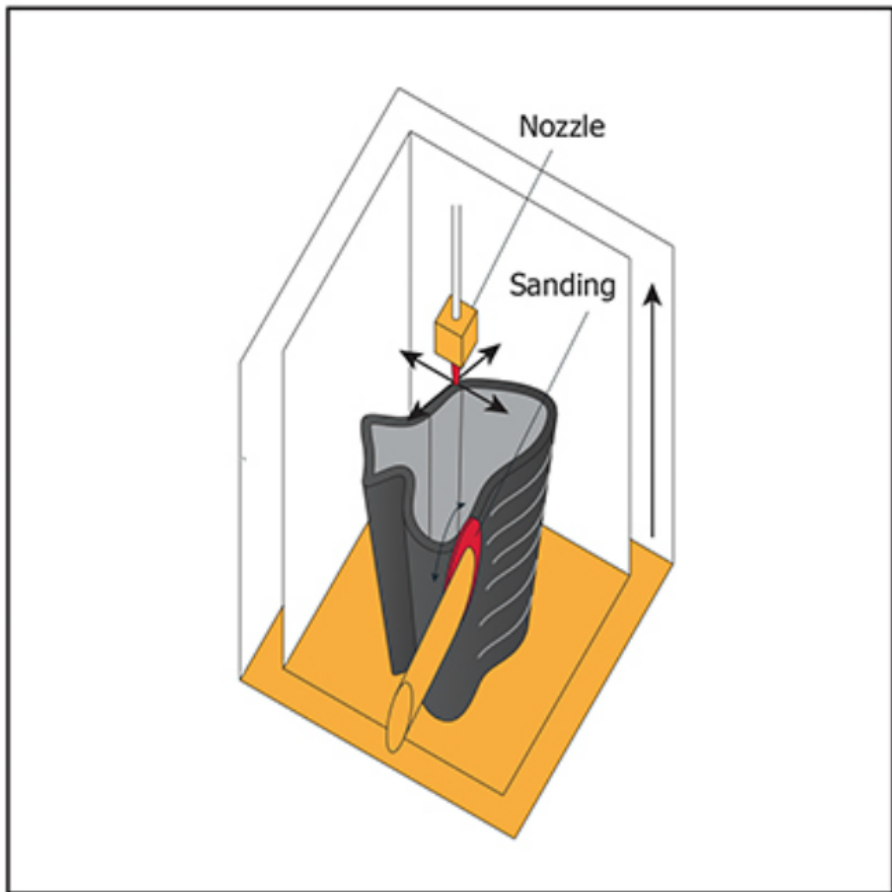


Fast
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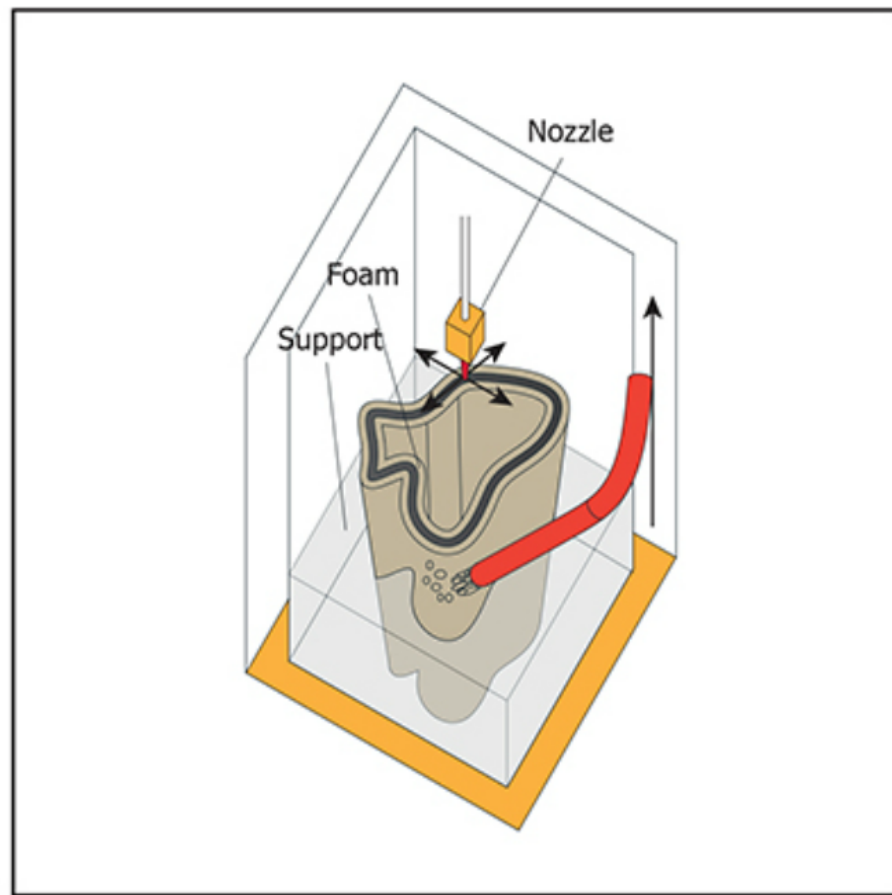


High
Less
Faste
Faste

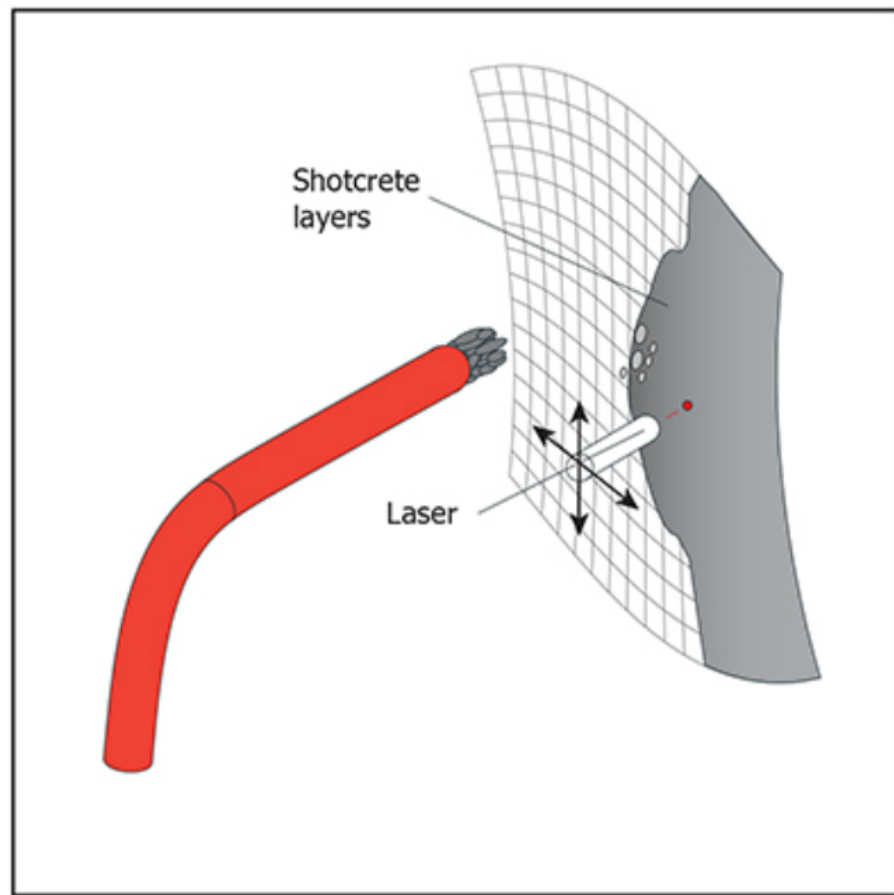
levated support

levated support

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revents dehydration of
ne concrete



Minim
Effici
Freef
Cont



Build
Freef
Fast p
High

FIELD OF AM

Initiatives

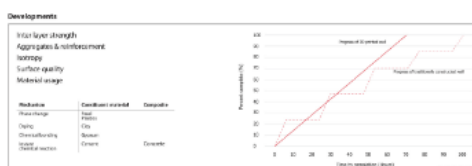
- FIBERTECH**
Control casting
Without new materials
- 3D Concrete printing**
Full solution
- 3D Bridge**
3D printer
- AM road technique**
CCTV (made by TruTech)

Characteristics

- Atropic
- Surface quality differs
- No internal reinforcement
- No aggregates
- Compact concrete flow for build
- Mixing support material
- Not concrete
- Strong
- Freeform
- Isotropic concrete
- Lost material

Related experts

AM	Concrete	Moulds	Concrete processing	AM Concrete research
<ul style="list-style-type: none"> Support: Major manufacturers AM: 3D printing AM: 3D printing AM: 3D printing 	<ul style="list-style-type: none"> Major manufacturers Major manufacturers Major manufacturers 	<ul style="list-style-type: none"> Major manufacturers Major manufacturers 	<ul style="list-style-type: none"> Major manufacturers Major manufacturers Major manufacturers 	<ul style="list-style-type: none"> Major manufacturers Major manufacturers Major manufacturers
Companies				



DEVELOPMENT

Concrete consistency and interlayer strength

Reinforcement

Concrete mortar

Binding agent

Freeform

Implementation

AM with a support material

Additive casting

G-code

Mixture and composition

Freeform and support

Resolution

Curing

Shootecrete

Customise

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Shootecrete

Customise

CONCLUSION: FUTURE VISION

Characteristics & Evaluation

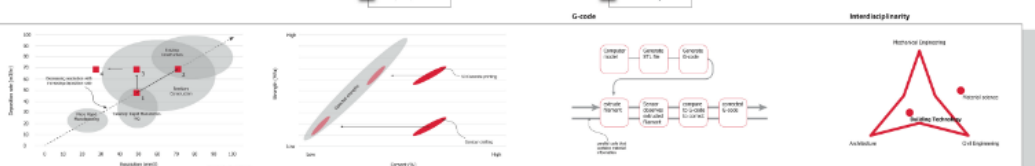
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- Fast process
- High surface quality due post processing

Advanced extruder

- Aligned fibres
- Controlled rebar layer strength
- Smooth surface
- Advanced extruded elements with different densities are extruded at once due to multiple extrusion points in the die. The extruder head can be used for different process applications.

PRODUCTS

- Gradient material**
Large structural elements with different distribution of aggregates and composition, DfAM without network.
- Core parts**
Print in low resolution, to integrate production speed. These elements will be covered or finished afterwards.
- Freeform**
Freeform, high-resolution elements. Joints of standard systems, and 3D reinforcement elements.



CONCRETE IN AN AM PROCESS

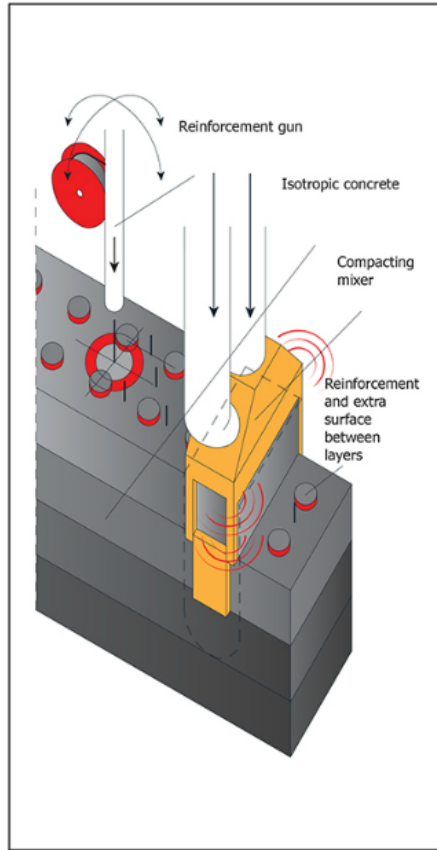
Freeform concrete processing

This report examines the additive manufacturing (AM) of concrete, its possibilities, feasibility and advantages over existing techniques. Traditional processing techniques are related to the characteristics of concrete and concrete does not fit well (factor here is below). The possibilities for products made with an additive process are endless, but not using existing production methods with additive ones, is still impossible. Although improved freeform production techniques are the aim of this research, this does not mean that more freedom in forms is by definition the target in concrete that AM can offer at the moment. From a number of points of view the implementation of additional functions in traditional products can be of great value.

A roadmap identifies how the technique has to evolve in order to implement the characteristic properties of concrete. Product ideas and an evaluation of the techniques shown in the roadmap are related to the development needs to achieve an increase in speed, surface quality and strength in the AM production technique, next to the requirements that have to be set regarding a matching best concrete mixture.

ROADMAP: future vision

Advanced extruder



Aligned fibres
Controlled mixture
Inter layer strength
Smooth surface

Advanced extruded elements with different densities are extruded at once due to multiple extrusion points in the die. The extruder head can be used for different process approaches



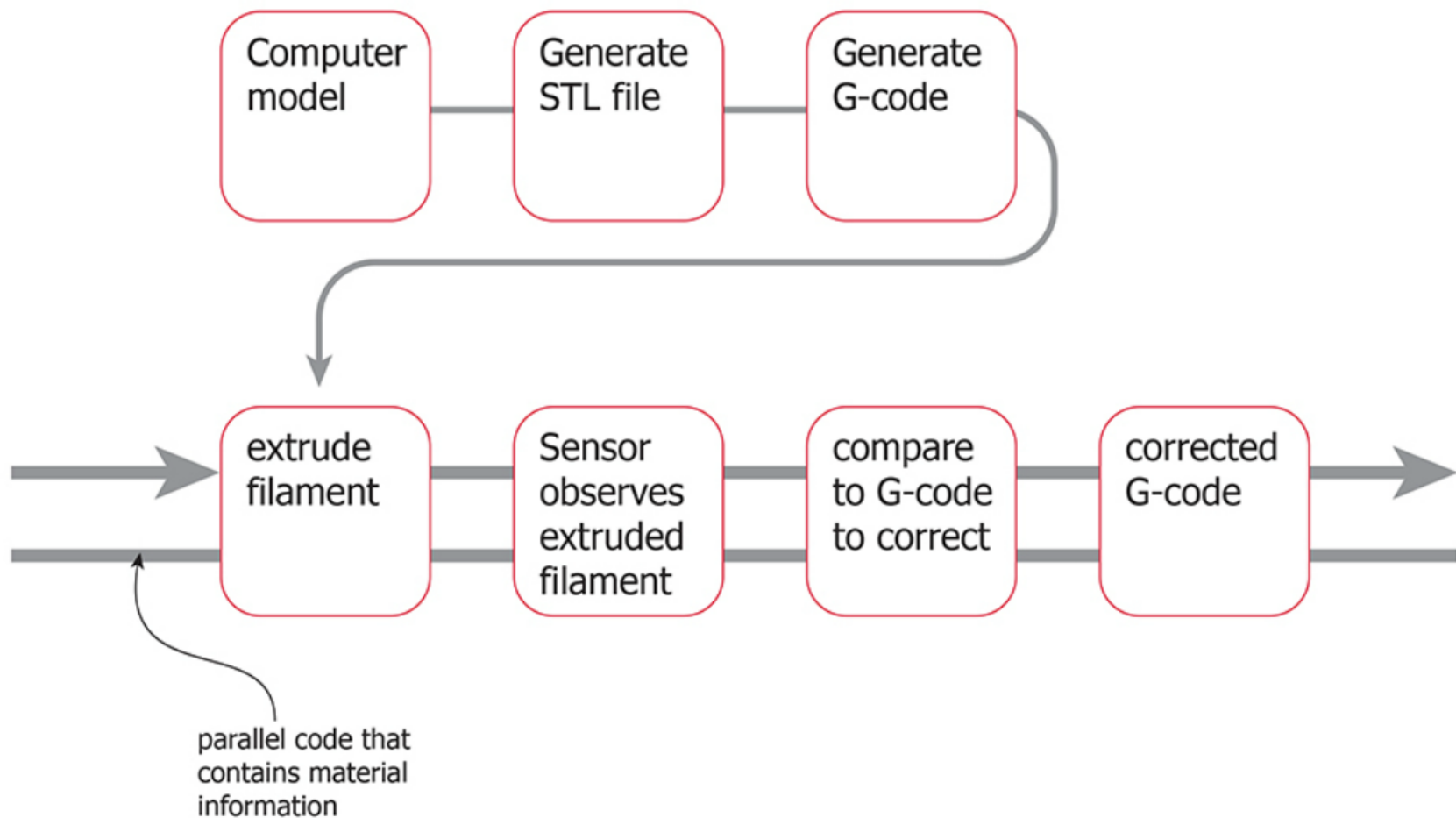
Process

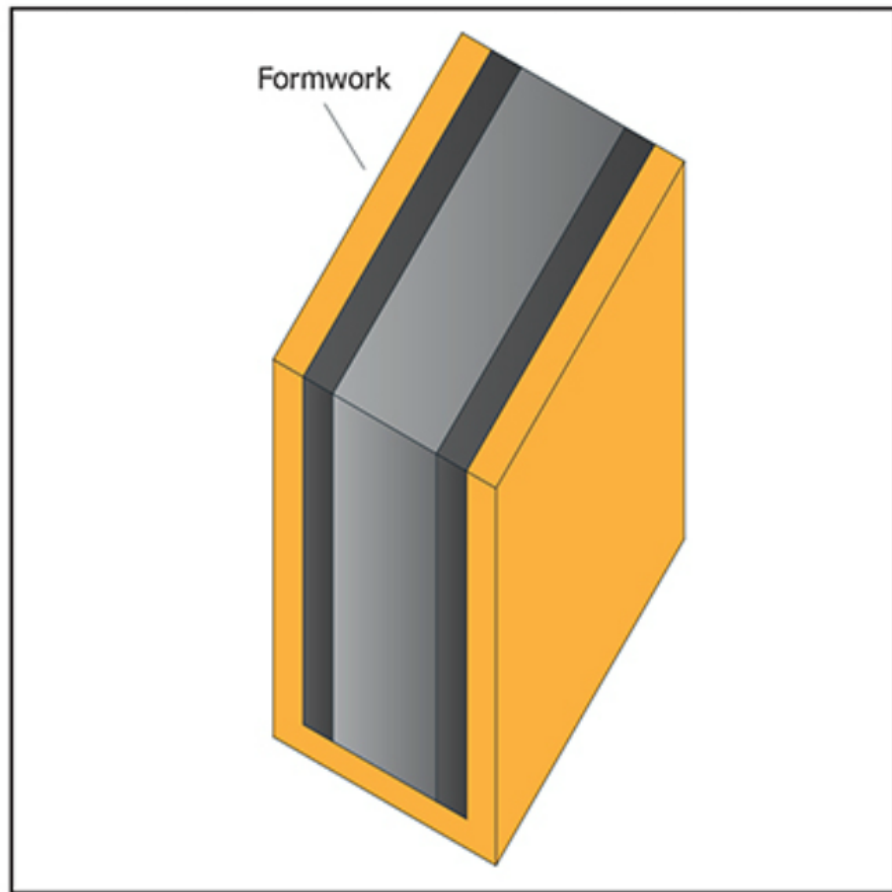
Control

Implement

PRODUCTS

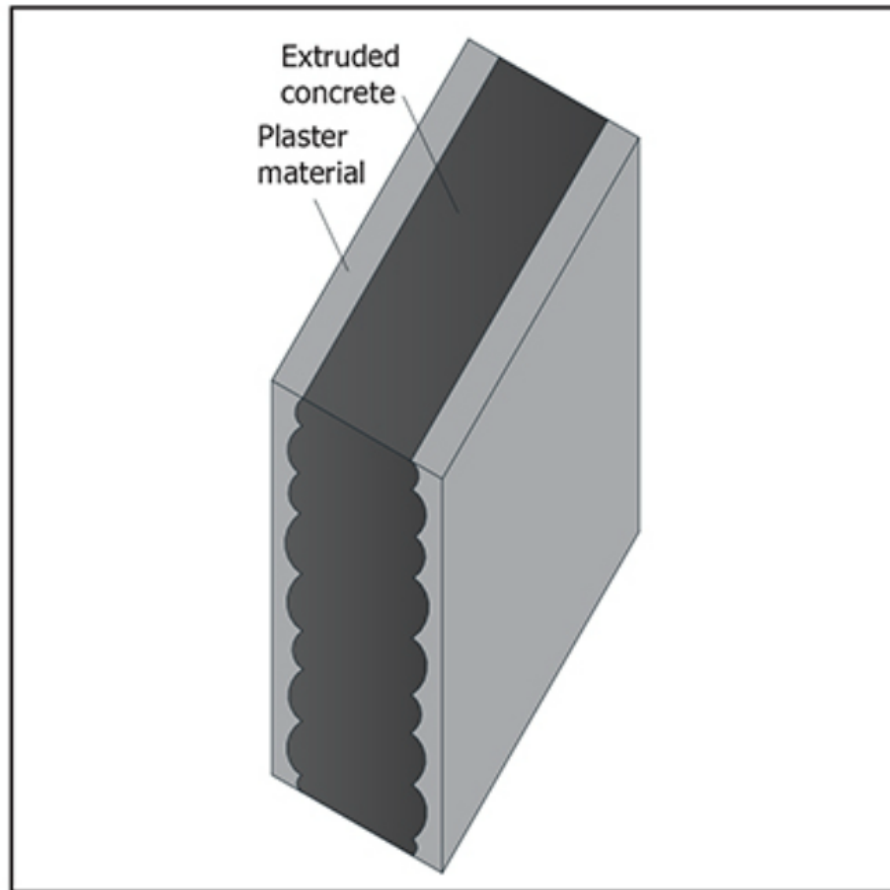
ion





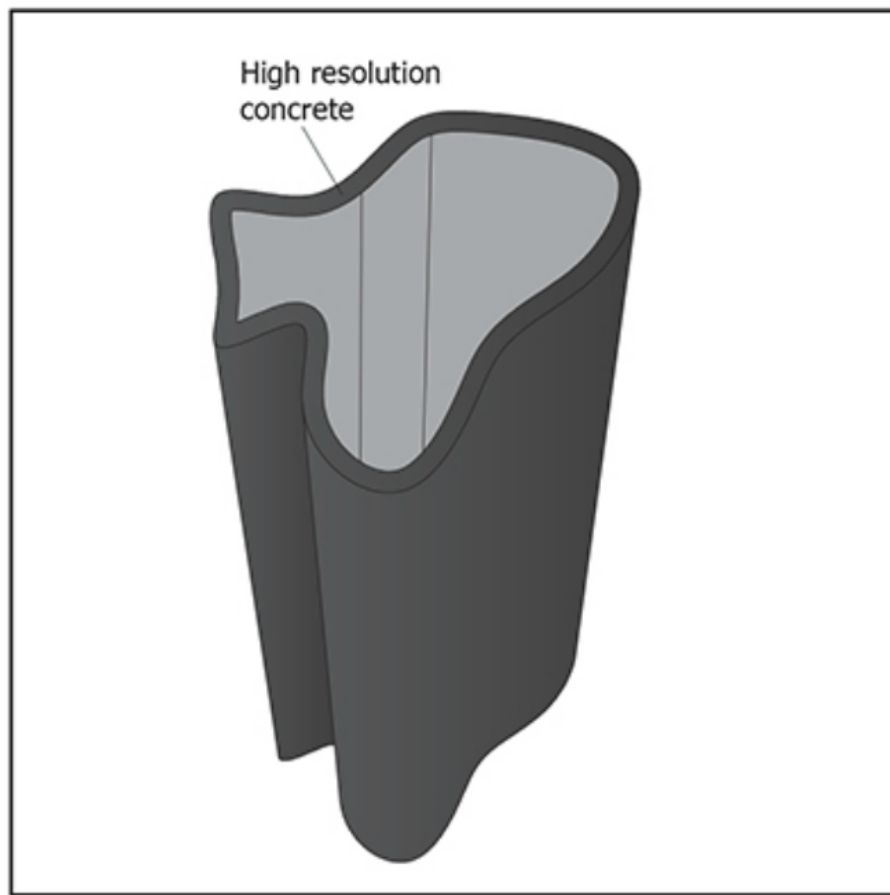
Gradient material

Large structural elements with different distribution of aggregates and composition. With or without formwork.



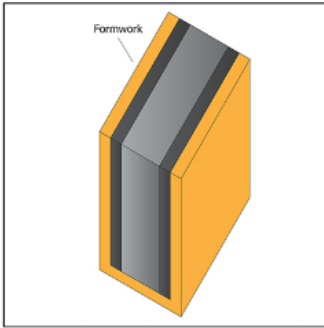
Core parts

Print in low resolution, to increase production speed. These elements will be covered or finished afterwards.



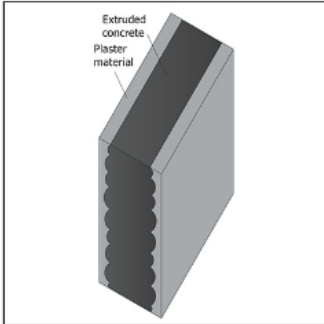
Freeform

Freeform, high resolution
elements,
Joints of standardized
systems, and
3D refurbishment
elements



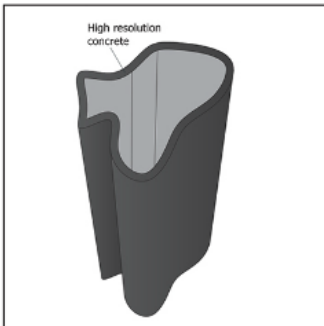
Gradient material

Large structural elements with different distribution of aggregates and composition. With or without formwork.



Core parts

Print in low resolution, to increase production speed. These elements will be covered or finished afterwards.



Freeform

Freeform, high resolution elements, Joints of standardized systems, and 3D refurbishment elements

ROADMAP: future vis

Threats
Add value

FIELD OF AM

Initiatives

1. Fibrecrete
Concrete walling without rebar mesh

2. 3D concrete printing
Full enclosure

3. 3D bridge
3.1m

4. AM road technique (CC)
asphalt by the truck

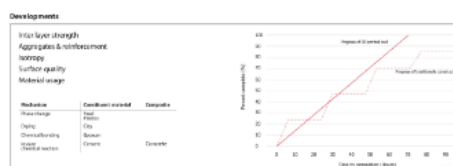
Related expertise

Concrete
Mortar
AM
Concrete research
AM with support material

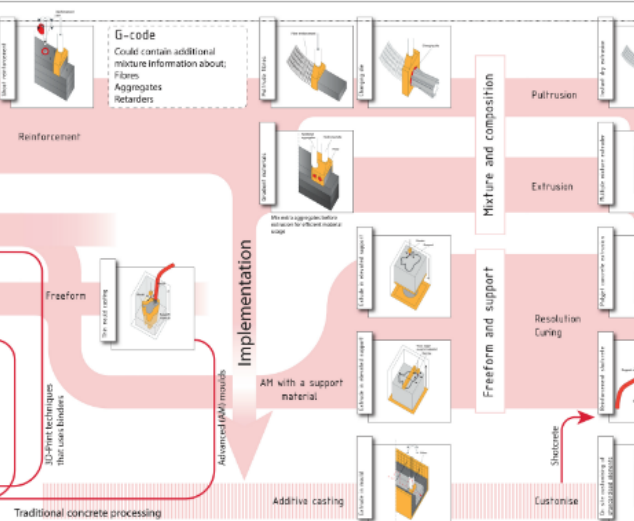
Moulds
Sinter
Metal

Concrete processing
Concrete
AM
Concrete research

Companies
AM
Concrete
Concrete research
AM with support material



DEVELOPMENT



CONCLUSION: FUTURE VISION

Hybrid techniques description

Instant dry extrusion (push-trusion)
High surface quality elements with built-in reinforcement and a wide range of material compositions.
eg. large concrete structural part

Orientated fibre reinforced concrete
More isotropic reinforcement
Less free form
More isotropic
Less material

Precast mill sand
Less free form
Less resolution needed
Faster printing process
Faster overall process

(Mixed) extrusion with elevated support printing
Less free form
Less resolution needed
Faster printing process
Faster overall process

Support net spraying
Prints a network of support for other layers and for reinforcement
The production level provides distribution of the network

Printed concrete structures
High resolution
High surface quality
Fast process

Characteristics & Evaluation

Fast Reinforced
Can be automated easily
High quality concrete (retracted at once)

Orientated reinforcement
Controlled material composition
Less free form
More isotropic
Less material

High surface quality
Less resolution needed
Faster printing process
Faster overall process

Minimizing printing time
Efficient support
Controlled material composition

Build around the reinforcement
Freeform
Fast process
High surface quality due post processing

Advanced extruder

Aligned fibres
Controlled rebar layer strength
Smooth surface

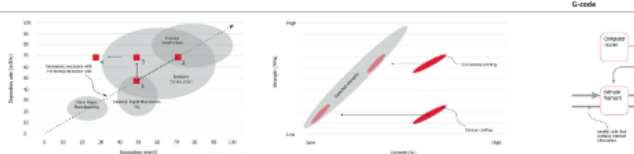
Advanced extruded elements
With different densities are oriented at once due to multiple extrusion points in the die. The extruded best can be used for different process applications

PRODUCTS

Gradient material
Large structural elements with different distribution of aggregates and composition, 100% without network

Core parts
Print in low resolution, to integrate production speed. These elements will be covered or finished afterwards

Freeform
Freeform, high resolution elements
Layers of standard systems, and 3D reinforcement elements



CONCRETE IN AN AM PROCESS

Freeform concrete processing

This report examines the additive manufacturing (AM) of concrete, its possibilities, feasibility and advantages over existing techniques. Traditional processing techniques are compared to the characteristics of concrete and concrete does not let itself relax here to behave. The possibilities for products made with an additive process are endless, but full-scale printing is still in its infancy. Although improved freeform production techniques are the aim of this research, this does not mean that more freedom in form is by definition the target in concrete AM. The AM can offer at the moment. From an engineering point of view the implementation of additional functions in traditional products can be of great value.

A roadmap indicates how the technique has to evolve in order to implement the characteristic properties of concrete. Product ideas and an evaluation of the techniques shown in the roadmap are related to the developments to achieve an increase in speed, surface quality and strength in the AM production technique, next to the requirements that have to be set regarding a matching best concrete material.

ROADMAP: future vision

Recommendations

Collaboration between faculties

- Architecture

- Civil engineering

- Material science

- Mechanical engineering

Build a printer to test and validate theoretical research

Conclusions

Concrete differs a lot from other AM materials

Processes need to be adapted to the material

Premature to look only at products

Multiple stage or combined techniques are important

Next steps in research

In depth research regarding feasibility of the future visions
Keep observing the competition to keep ahead of them
Publish results

Questions?

CONCRETE
in an AM process

Freeform concrete processing