# Challenges Ahead!
# A Manufacturer's Perspective

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REHVA
Federation of European Heating, Ventilation and Air-conditioning Associations

*HVAC sector challenges ahead us*
*REHVA Seminar – REHVA Annual Meeting 2017, 2-4 April 2017, London, UK*

İZMİR KÂTİP ÇELEBİ ÜNİVERSİTESİ 2010

eneko®

# 3D printing of HVAC Components, Units & Systems

**CONTENT**

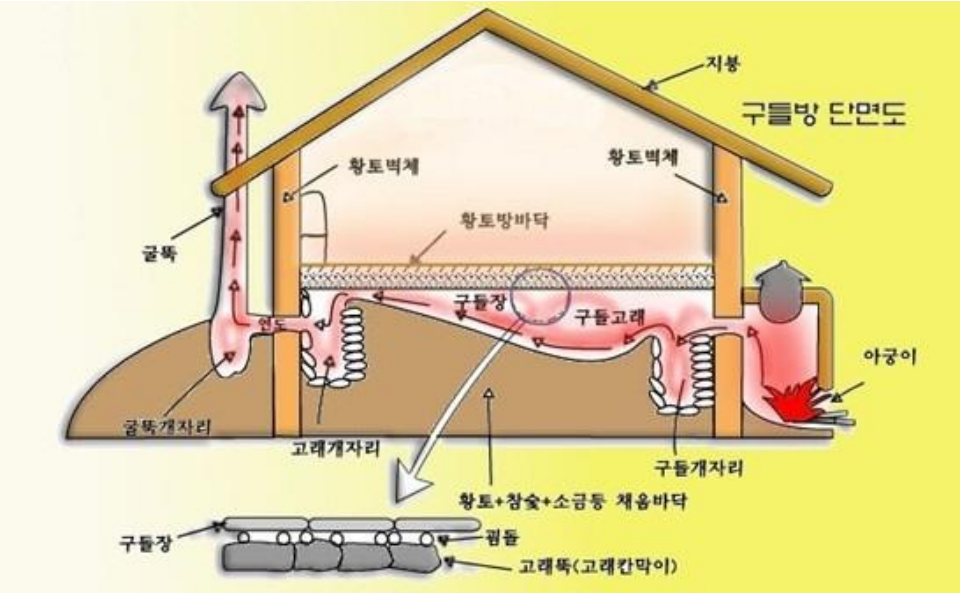
- **Integrated Building Design in the Greco-Roman World**
- **Trends, Innovations, Research & Development That Will Change HVAC future**
- **Additive Manufacturing (3D Printing) Technology and HVAC:**
  - **3D Components Manufacturing**
  - **3D Equipments Manufacturing**
  - **Integrated Design and 3D Building Construction**

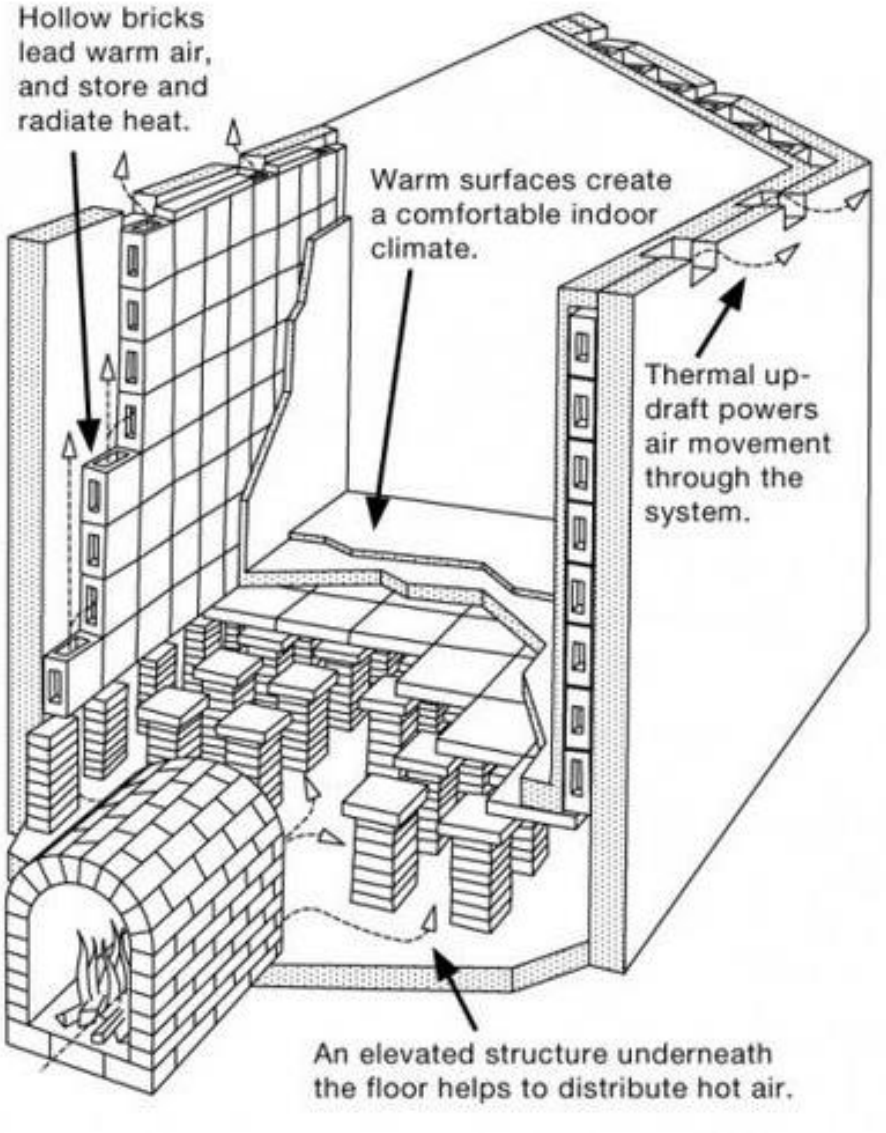
**3D CM - 3D EM - 3D BC**

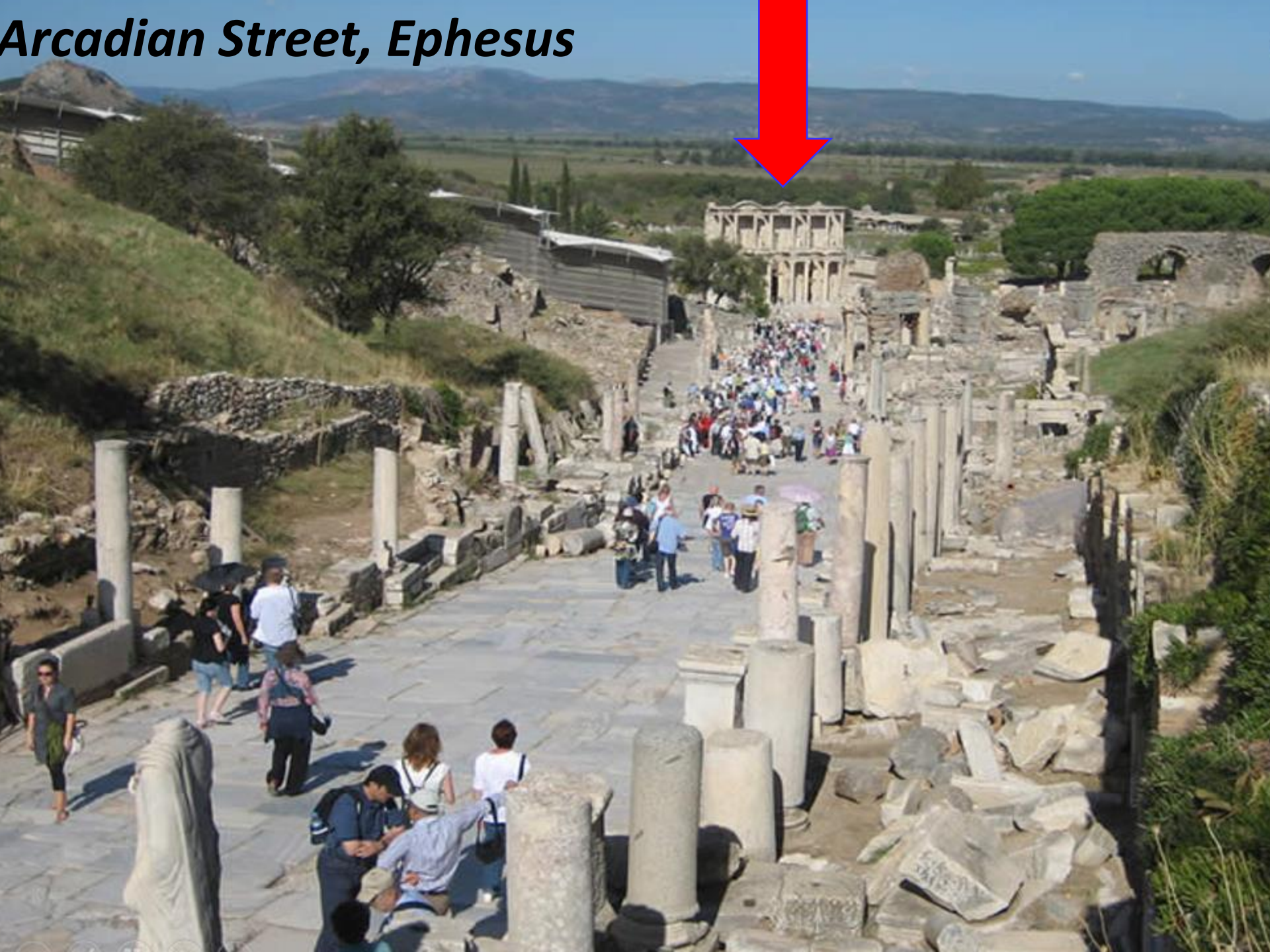
# Fully Integrated Solutions:

**Hypocaust – Hypocaustum**
**Roman Bath and**
**Sanitary System**

**Ondol**
**Korean Cooking and**
**Underfloor Heating Systems**




Arcadian Street, Ephesus


EPHESUS
Library of Celcius
(Celsus)

Spain

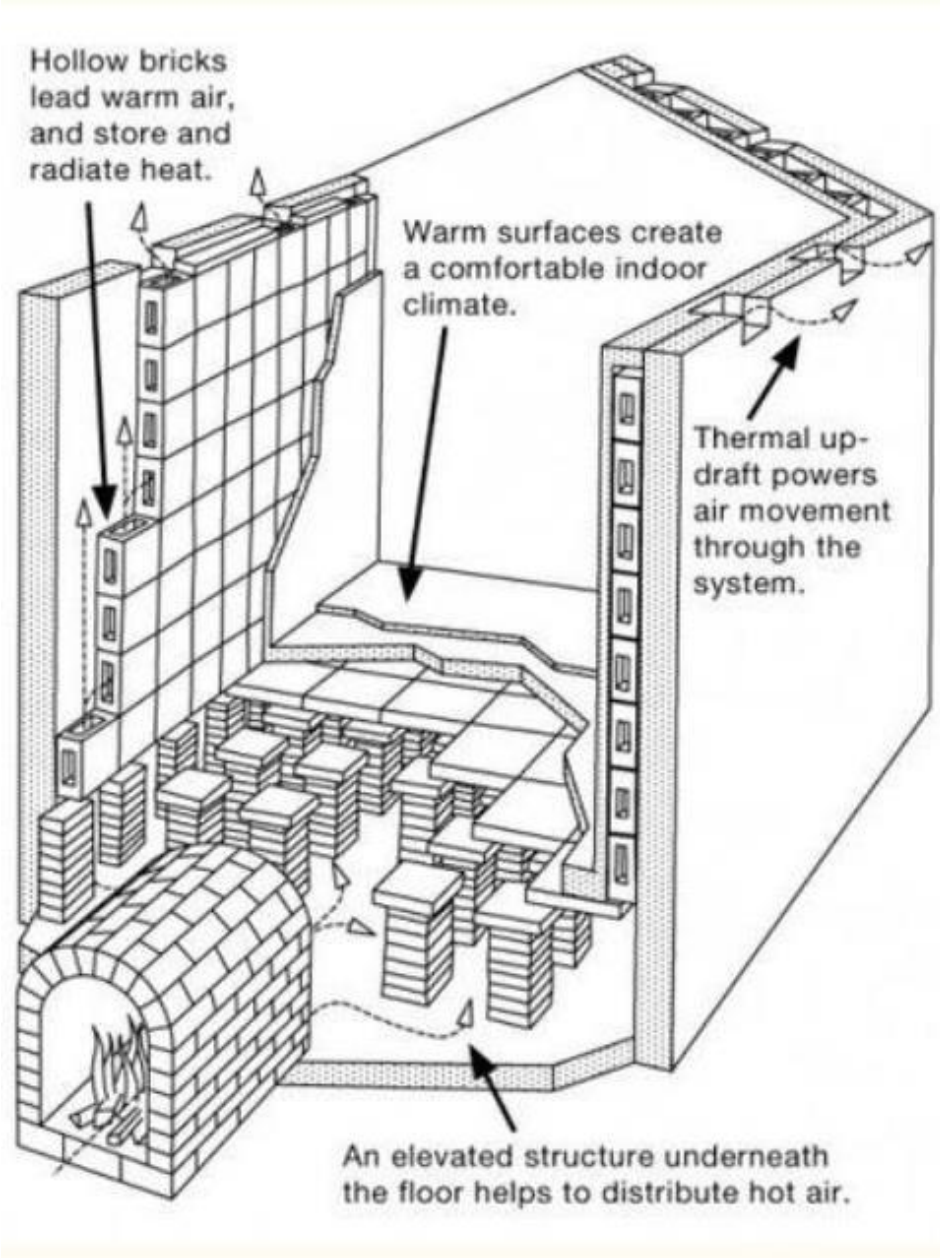
Romania

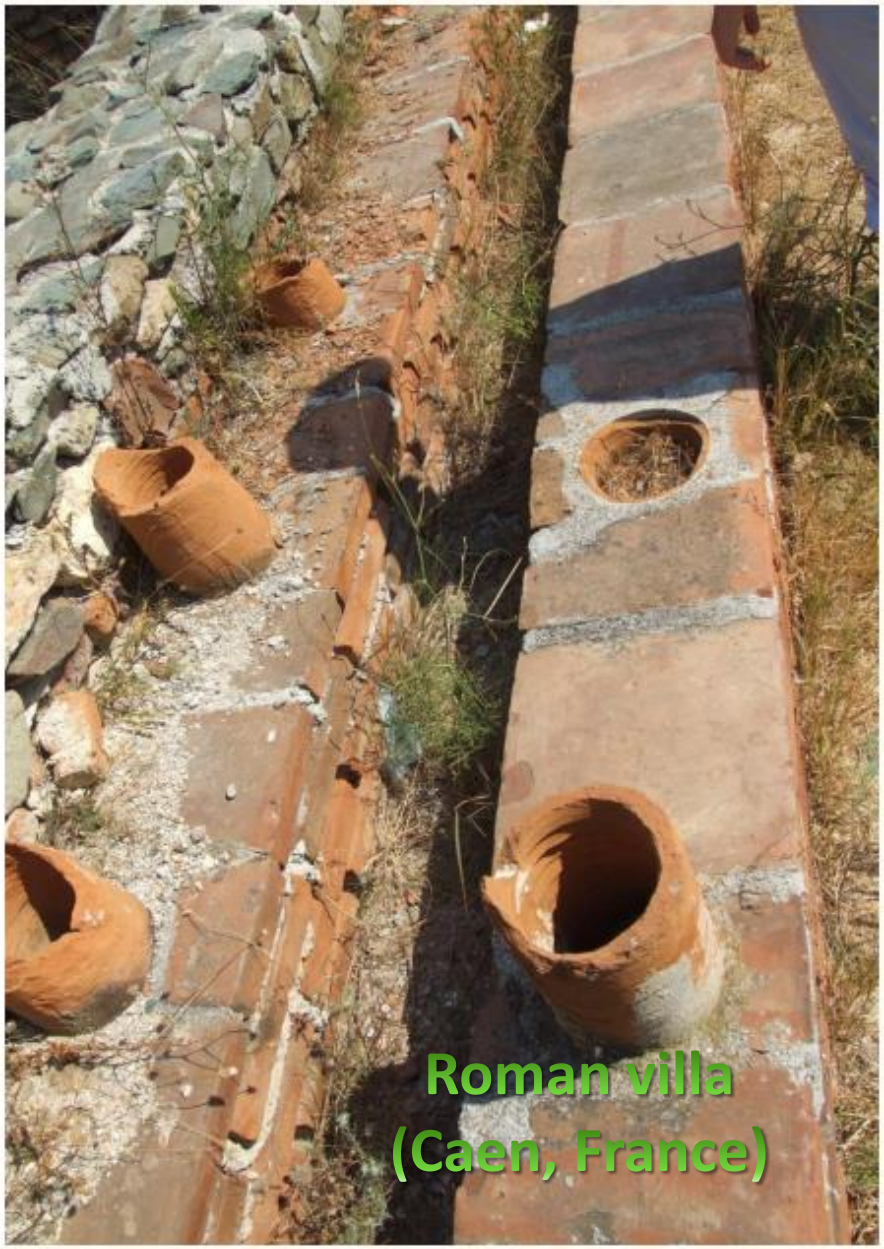
Britain

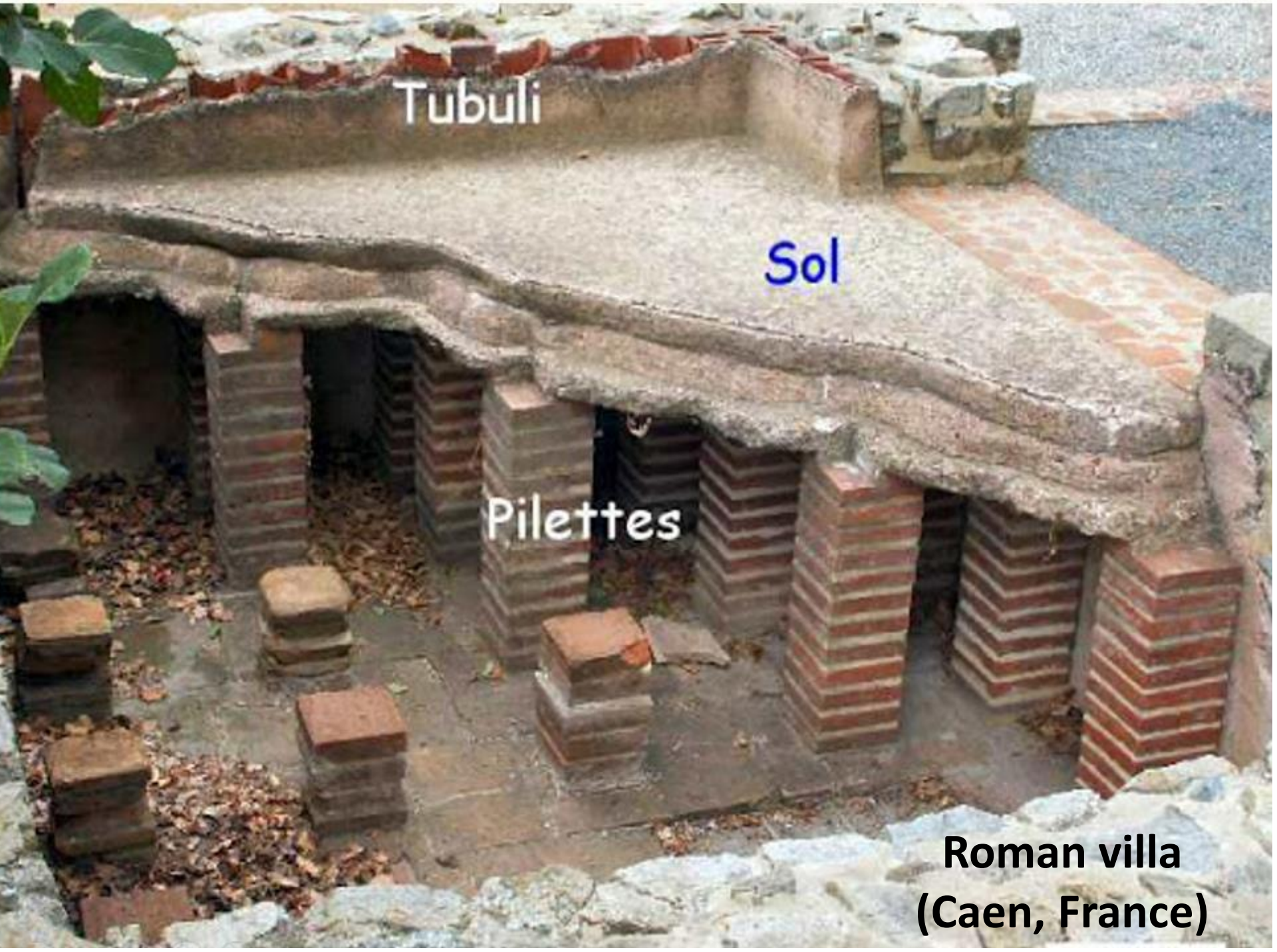
Turkey

**Ephesus Latrines (Public Toilets)**

# A hypocaust (Latin *hypocaustum*)



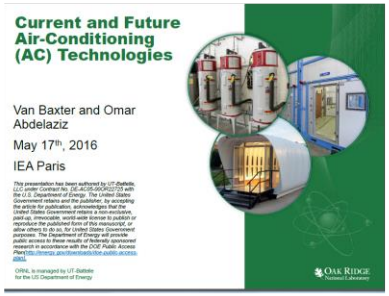



**Roman villa (Caen, France)**

**A Futuristic Surf // 21 SOURCES (2014 – 2016)**

(web sources on Innovations and trends That Will Change HVAC future
DOE BTO Reports - ORNL Report – NERL Report – Papers)

| | | | | | |
|---|---|---|---|---|---|
| 1 | ADV.VAPOUR COMP. TECH. UD | 10 | EDUCATION | 19 | NON - VAPOUR-COMPRESSION |
| 2 | AIR FILTRATION | 11 | ENERGY RECOVERY | 20 | RECYCLING OF MATERIAL |
| 3 | ALTERNATIVE ENERGY | 12 | ENERGY STORAGE | 21 | REGULATIONS |
| 4 | BIM | 13 | INSULATION | 22 | SIMULATION TOOLS |
| 5 | BUSINESS MODEL | 14 | INT. DES. - BUILDING ENVELOPE | 23 | SMART EQUIPMENT and SYSTEMS |
| 6 | CLIMATE SPESIFIC HVAC | 15 | INTEGRATED A/C TECH. | 24 | SMART SALES and MAINTENANCE |
| 7 | CONTROL | 16 | INTEGRATED BUILDING DESIGN | 25 | SYSTEM |
| 8 | DESIGN MODELING | 17 | MIX SYSTEM (COMP and NON-COMP) | | |
| 9 | MULTIPLE ENERGY SOURCES | 18 | MOBILE PERSONEL SYSTEM | | |






| | |
|---|---|
| 1 | ADV.VAPOUR COMP. TECH. UD |
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| 5 | BUSINESS MODEL |
| 6 | CLIMATE SPESIFIC HVAC |

| |
|---|
| Vapor Compression using alternative lower GWP refrigerants |
| **Heat pump** for low temperature (Cold Climate) |
| High-Performance Air Cycle **Heat Pump** |
| Low-GWP A/C System with Ultra-Small Centrifugal Compressor |
| High-Efficiency Low-GWP Compressor |
| Electronic air cleaners are 40x more efficient than a standard filter |
| Thermally Driven Air Conditioning |
| Geothermal **Heat Pumps** |
| The Use Of Solar Energy |
| Living algae buildings |
| Solar PV powered DC HVAC system |
| Mastering and using new tools like Building Information Modeling (BIM), building information systems, and lean management. |
| Contractors participating in one of five different business models instead of the “relatively homogeneous” market we have today. |
| A radically altered environment characterized by rising specialization, |
| A continued push toward globalization, etc. |
| Retrofit and service work will experience explosive growth in demand |
| Enable climate specific HVAC solutions |

**Heat Pumps**

| | |
|---|---|
| 7 | CONTROL |
| 8 | DESIGN MODELING |
| 9 | MULTIBLE ENERGY SOURCES |
| 10 | EDUCATION |
| 11 | ENERGY RECOVERY |
| 12 | ENERGY STORAGE |
| 13 | INSULATION |
| 14 | INT. DES. - BUILDING ENVELOPE |

| |
|---|
| A motion-activated Air Conditioning system |
| **Sensor**-Enhanced Ventilation |
| **Smart** Homes |
| **Fully Automated** Homes |
| **Smart** HVAC Industry Smarter technologies (Smartphone apps, etc) |
| Microcontroller technology |
| **Dynamic modeling** of HVAC equipment. |
| Dual-Fuel Heat Pumps |
| Impact On HVAC Jobs |
| Harnessing Heat from a Computer |
| Ice bar- Ice-Powered Air Conditioning |
| Seasonal energy storage systems |
| Quiet Duct Wrap |
| **3-D Printed Building Component** |

**Smart Solutions**

**3D Printing Building Component**

| | |
|---|---|
| 15 | INTEGRATED A/C TECHNOLOGIES UD |
| 16 | INTEGRATED BUILDING DESIGN |
| 17 | MIX SYSTEM (COMP and NON-COMP) |
| 18 | MOBIL PERSONEL SYSTEM |

# Heat pump Digitally Fabricated Buildings

| |
|---|
| **Heat Pump** System for HVAC and Sanitary Hot Water |
| Air Source Integrated **Heat Pump** HVAC and Sanitary Hot Water |
| Combinerd Water Heater, Dehumidifier and Cooler |
| Natural Gas Boiler and CO2 **Heat Pump** |
| Natural Gas A/C and **Heat Pump** |
| Multifunction Gas Fired **Heat Pump** |
| integrated design for Sustainable Buildings - holistic design |
| Integration of A/C and Other Building Systems |
| **Digitally Fabricated** Buildings |
| Separate Sensible and Latent Cooling Systems |
| Personal Cooling Systems |

| | |
|---|---|
| 19 | NON - VAPOUR-COMPRESSION |
| 20 | RECYCLING OF MATERIAL |
| 21 | REGULATIONS |
| 22 | SIMULATION TOOLS |

| |
|---|
| **DEVap** Air Conditioning |
| **NanoAir™** System Architecture |
| **new adsorbtion pairs** |
| **Thermally driven** (absorption) |
| Solid-State (**thermoelectric, magnetocaloric**) |
| **Membrane** cooling systems |
| Electro-mechanical (**evaporative, thermoelastic**) |
| **Elastocaloric** |
| **Electrocaloric** |
| The Use Of Recycled Materials |
| Regulations Always Evolve |
| Increase in environmental concern |
| Complying needs of zero energy buildings |
| Energy Analysis Software |
| **Smart** HVAC Industry - Better measurements of building environments |
| Making building services more resilient |

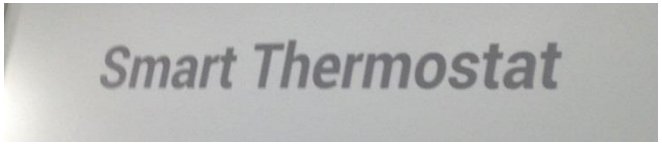
**Non-Vapour Compression**

| | |
|---|---|
| 23 | SMART EQUIPMENT and SYSTEMS |
| 24 | SMART SALES and MAINTENANCE |
| 25 | SYSTEM |

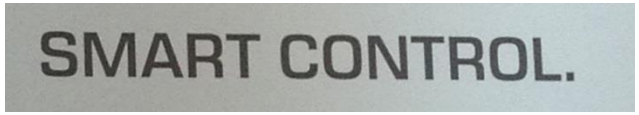
**Smart..Smart..Smart**

| |
|---|
| HVAC is getting **smart** |
| More Than Just Smart Controls…**Smart** EVERYTHING |
| HVAC is getting connected |
| HVAC businesses are joining the **digital age** |
| More **Integration** |
| User-Friendly Controls |
| **Intelligent self**-learning systems |
| Self-checking systems |
| Systems with seamless **remote access**, diagnosis and control functionality |
| Systems with the flexibility |
| **Smart** Thermostats |
| Utilisation of **cloud** technologies |
| HVAC venue **real time** performance demonstration |
| low pressure VAV diffusion design |
| **Smart** HVAC Industry - Mobile technologies to set up preventative maintenance and service programs. |
| HVAC Maintenance and Service will Become more Efficient through **Mobile** |
| **Automated** Fault Diagnosis (AFD) |
| **Smart** HVAC Industry -Automated their sales and service processes |
| On-Demand Hot Water Recirculator |
| VRF Systems (wll grow) |

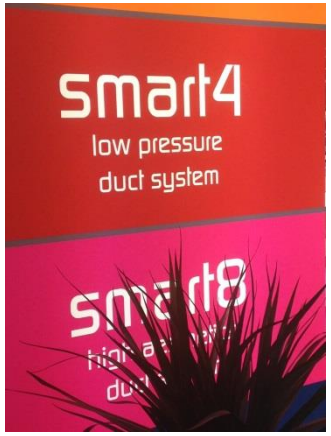


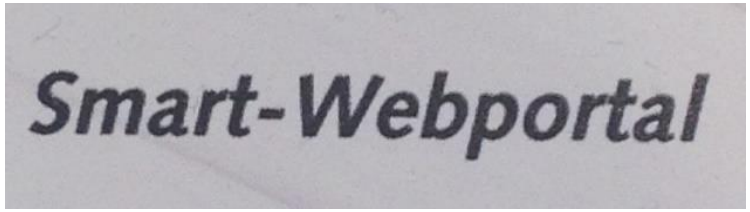






ISH
Frankfurt
2017




| • Integrated Design In Case Of Digital Fabricated Buildings.<br>(*) Energy Procedia 96 ( 2016 ) 212 – 217 | • 3-D Printed Building Component<br>(*)11 Innovations That will Change HVAC Forever |
|---|---|
| **Integral design of all building accessories** like internal heating, ventilation, and air conditioning (HVAC), water supply, and drainage network installations is essential when **applying additive manufacturing.. Additive manufacturing has potential to be "the next big step forward"**, because it allows advanced and brave design **and freeform constructions** inspired by nature. **Design Application** of large-scale **additive manufacturing systems** in the AECO industry **is in early research phase**. | "It may seem a **little far-fetched**, **but** 3-D printing has advanced rapidly over the last few years, so expecting products like **3-D printed A/C systems could very well be a reality one day**. In fact, a company called Emerging Objects has already created a **3-D printed "brick" that draws moisture out of an area to cool it**. While this simple innovation can't be used in extreme temperatures, and **we're still a far cry from 3-D printed air conditioners**, it's just one example of the power of such a simple technology. We never know what tomorrow may bring". |

# Emerging Technology Hype Cycle

Consumer 3D Printing

Enterprise 3D Printing




Years to mainstream adoption:

less than 2 years | 2 to 5 years | 5 to 10 years | more than 10 years | obsolete before plateau

gartner.com/SmarterWithGartner

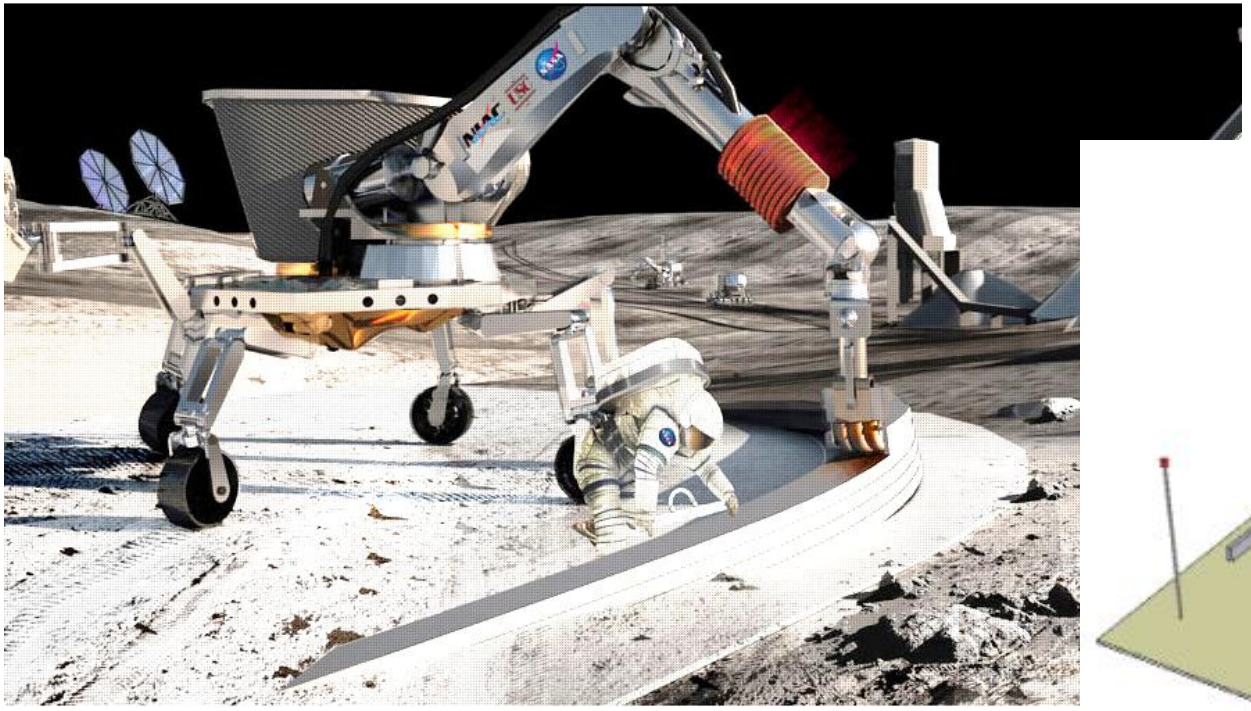


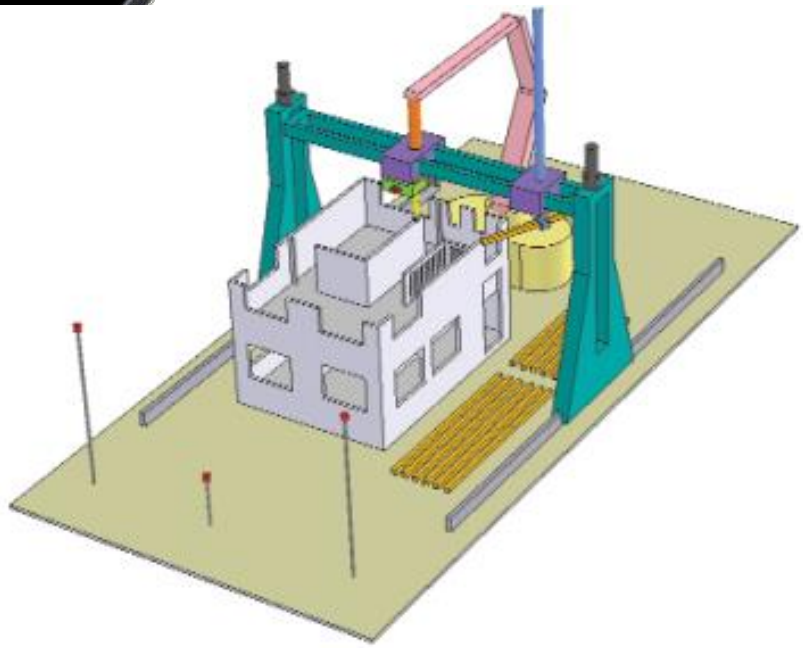
Gartner

Table 1. Examples of AM techniques available today, classified by basic principle according to ASTM F2792-12a [29] and class of materials.

| Basic Principle | Class of Material | | |
|---|---|---|---|
| | **Polymer/Organic** | **Metal** | **Ceramic** |
| Binder jetting | | 3D printing [1] [30] | 3D printing [1] [31,32] |
| Directed energy deposition | | Laser Engineered Net Shaping/LENS™ [33], Directed Light Fabrication/DLF [34], Direct Metal Deposition/DMD [35] | Laser Engineered Net Shaping/LENS™ [36] |
| Material extrusion | Fused Deposition Modelling, FDM [37] | Fused Deposition Modelling, FDM [38,39]; Multiphase Jet Solidification, MJS [40] | Fused Deposition Modelling, FDM [41]; Robocasting [42]; Freeze-form Extrusion Fabrication, FEF [43,44] |
| Material jetting | Direct Printing, DIP [45]; Multi-Jet Modeling/MJM or Polyjet Modeling/PJM [46]. | Direct Printing, DIP [47] | Direct Printing, DIP [32] |
| Powder bed fusion | Selective Laser Sintering, SLS [2] [48] | Selective Laser Melting/SLM[2] [49]; Selective Laser Sintering, SLS[2] [50]; Direct Metal Laser Sintering, DMLS [51]; Electron Beam Additive Manufacturing, EBAM [52] | Selective Laser Sintering/SLS[2] [32,53] |
| Sheet Lamination | Laminated Object Manufacture, LOM [54,55] | Laminated Object Manufacture, LOM [56,57]; Plate Diffusion Brazing/PDB [58] | Laminated Object Manufacture, LOM [32] |
| Vat photo-polymerization | Stereolithography/SLA [59] | Stereolithography [60,61] | Stereolithography/SLA [32,62,63,64] |

# 2004-2014? Contour Crafting can Build Homes in a day





…**embedded in each house all the conduits for electrical, plumbing and air-conditioning.**

Behrokh Khoshnevisk, Houses of the Future Construction by Contour Crafting Building Houses for Everyone, POLICY BRIEF, 2004, UNIVERSITY OF SOUTHERN CALIFORNIA URBAN INITIATIVE

# 2015

## World's first 3D-printed apartment building constructed in China

A Chinese company has successfully 3D printed a five-storey apartment building and a 1,100 square metre villa from a special print material.

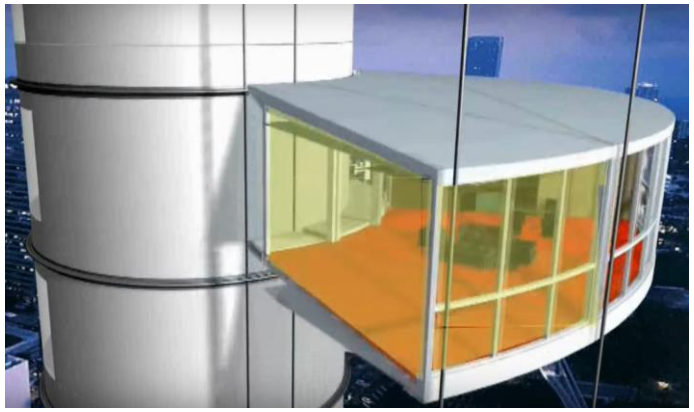
**2016**

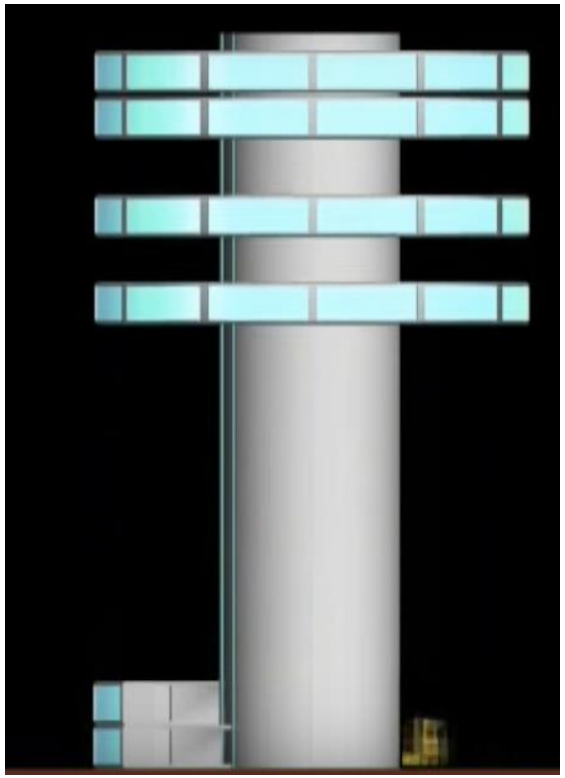
# Dubai unveils world's first 3D-printed office building

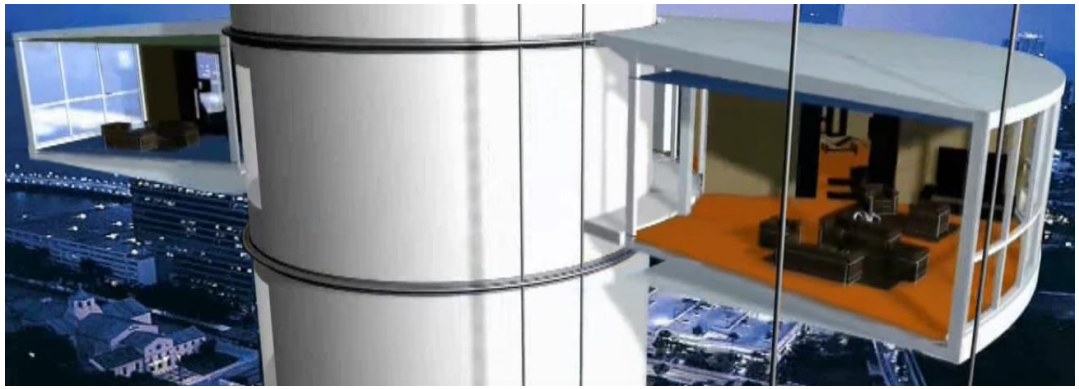
After nearly a year in development, Dubai unveils an open-plan office constructed using an industrial 3D printer.

# 30 Greatest 3D Printed Houses & Structures in the World, as of March 6th, 2017

# Dynamic (Kinetic) Architecture

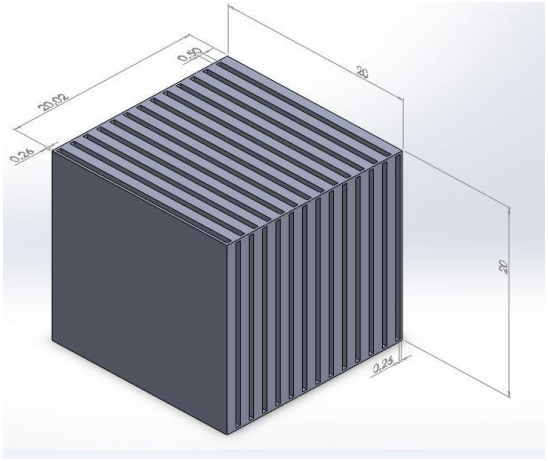


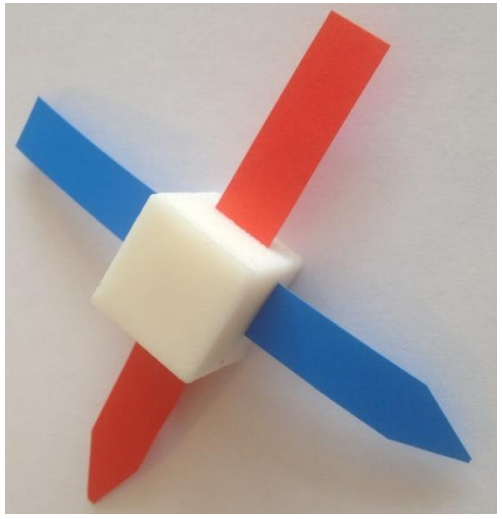




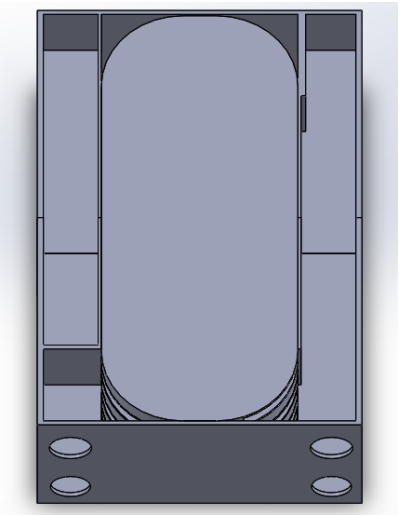
# Start-up studies at ENEKO and İzmir Katip Çelebi University

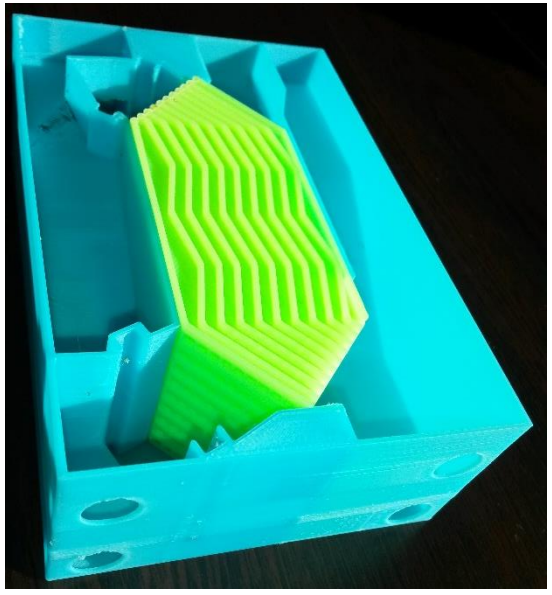
## 3D CM



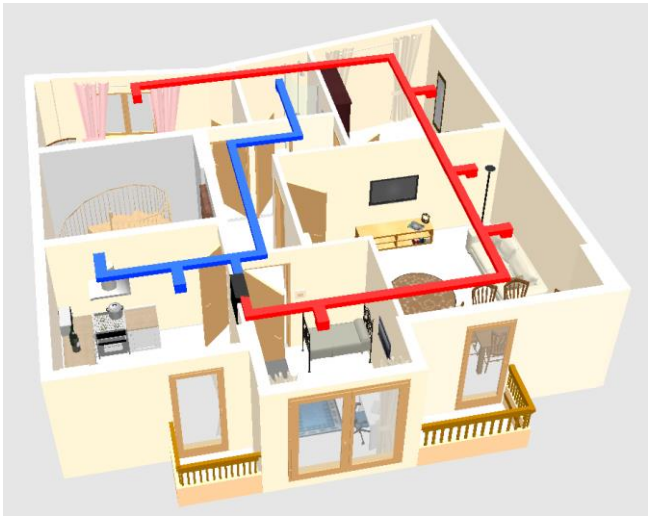


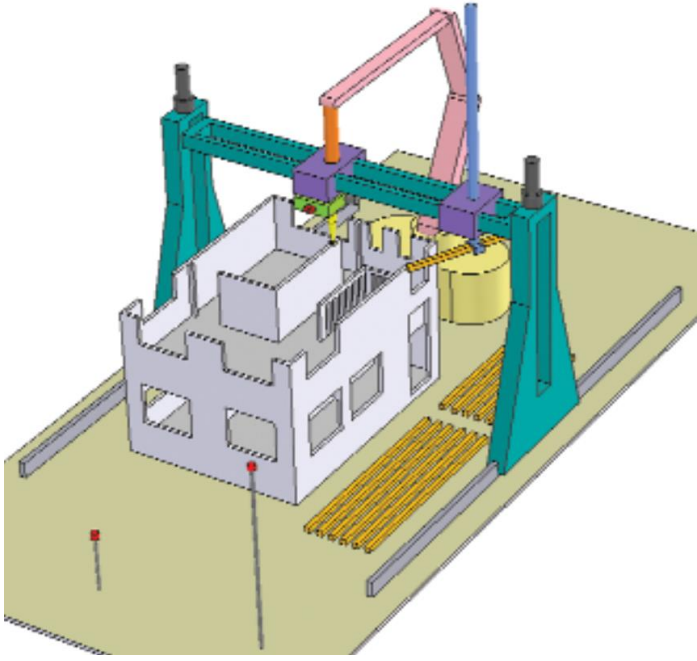
## 3D EM





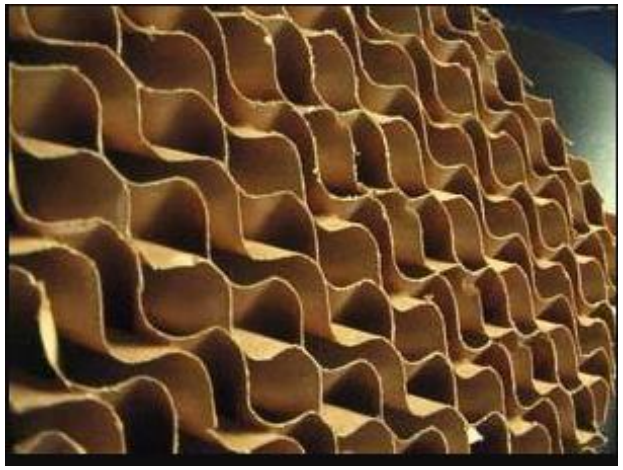
## 3D BC





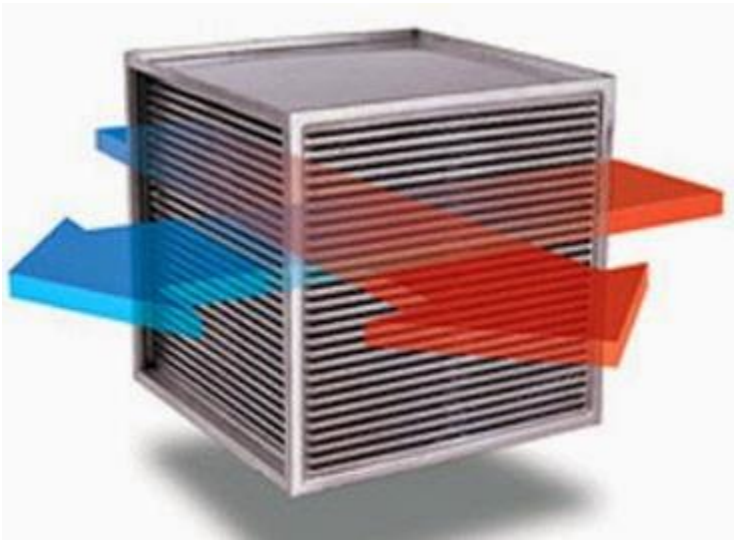
# 3D CM: Heat Exchanger

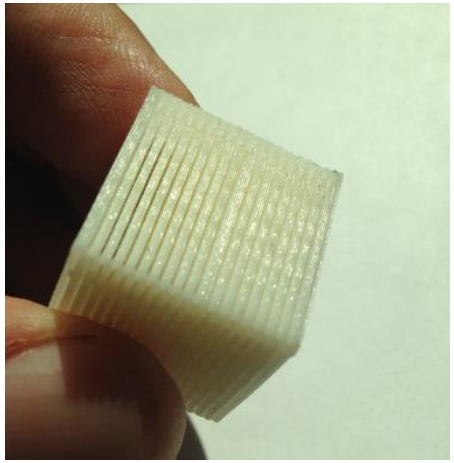
**Cellulose**

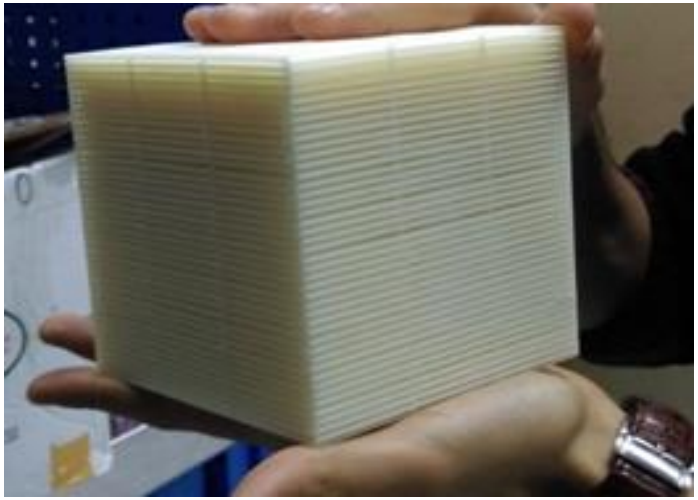


**Pet**

**Aluminium**

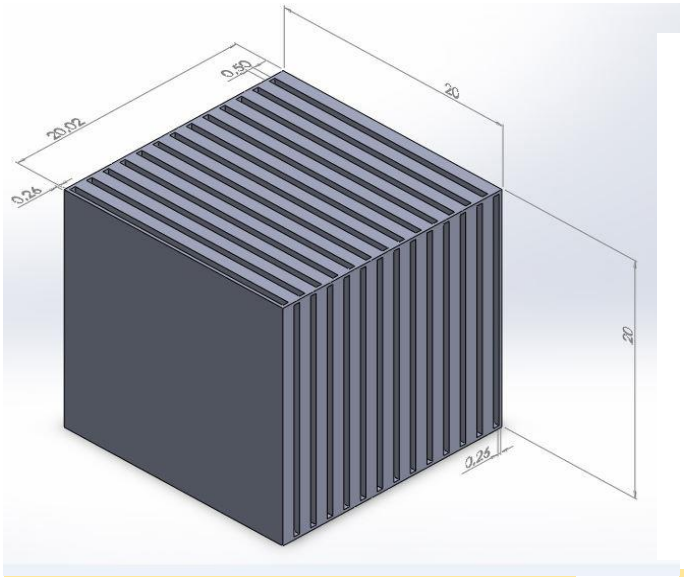


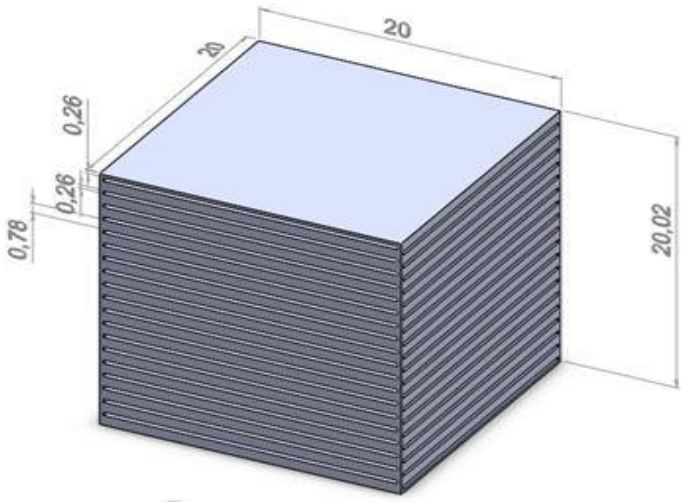




**ABS, Nylon, Polycarbonate, ASA, PPSF/PPSU, metals and many others**

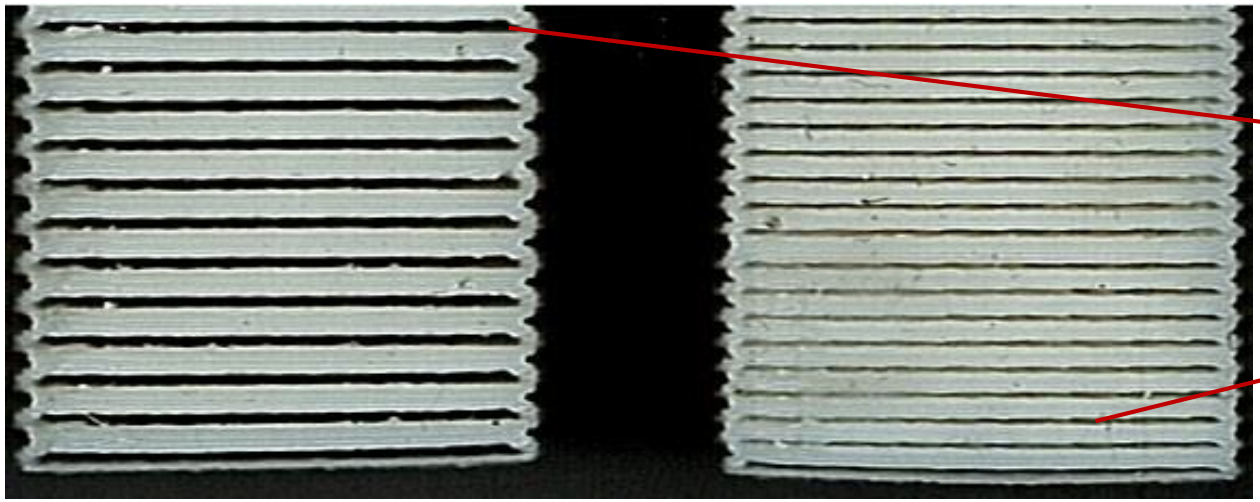
# 3D CM: Heat Exchanger, Supported manufacturing!



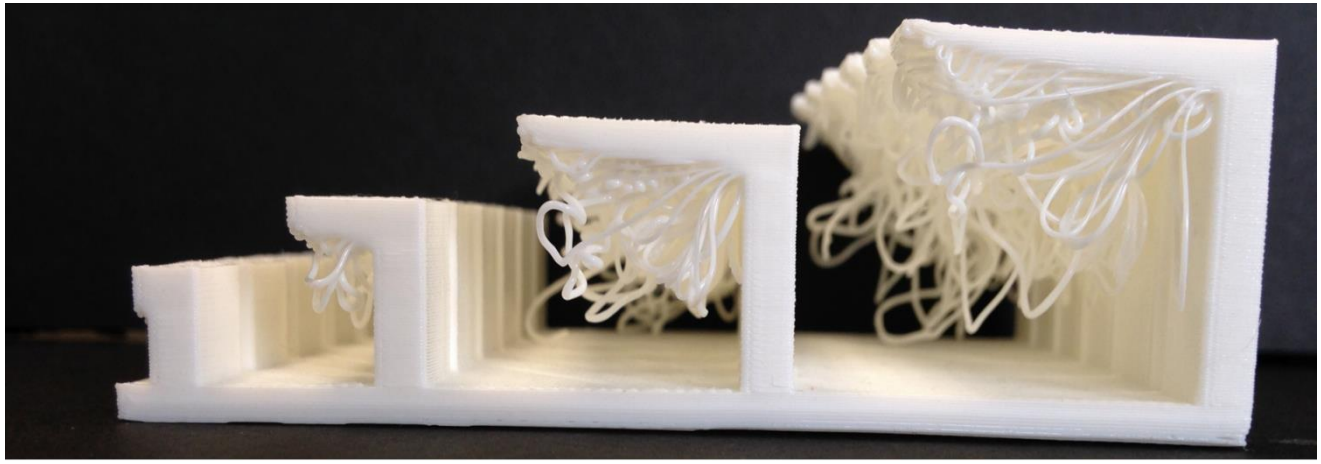

260µm gap and
520 µm layer thickness

260µm gap and
260 µm layer thickness

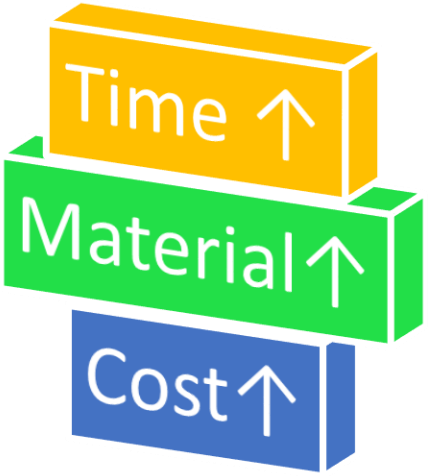


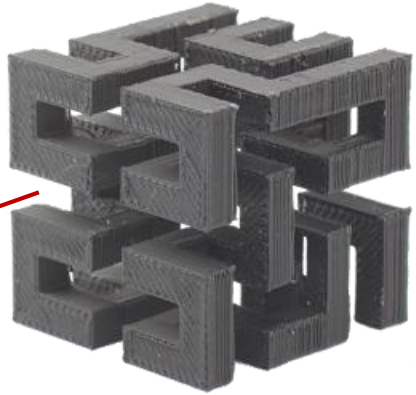
Gaps should
be supported!

# 3D CM: Heat Exchanger, Supported manufacturing!

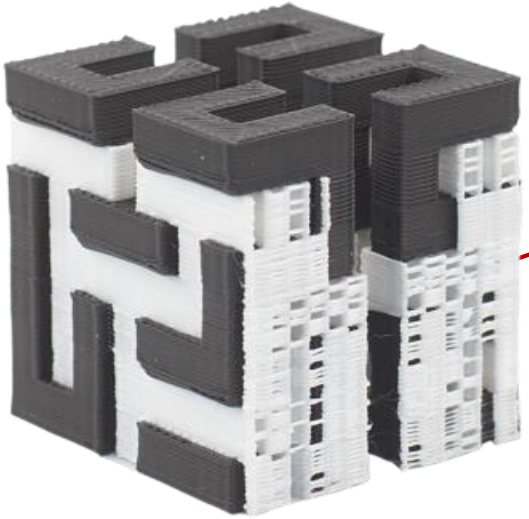


Failed Horizontal Overhangs



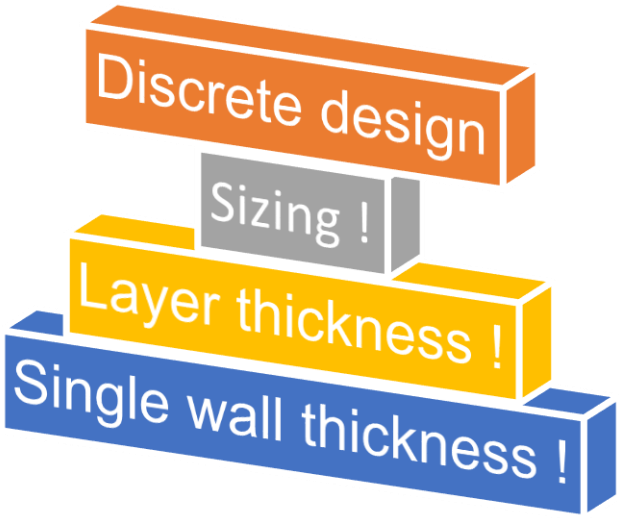



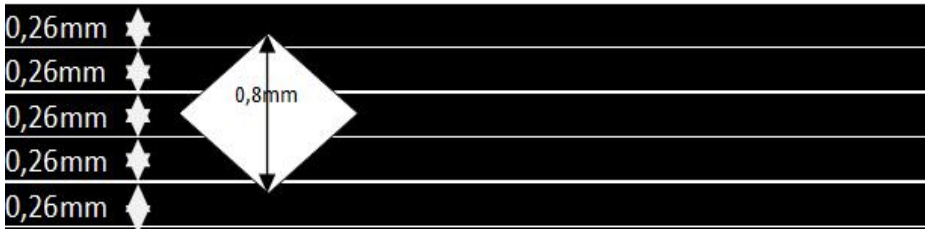
Support is cleaned

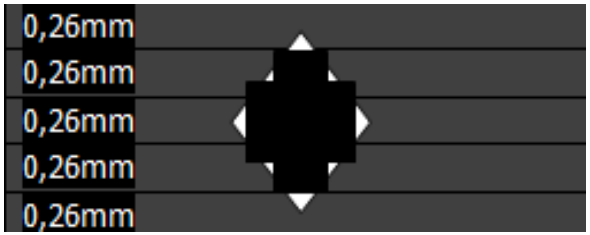


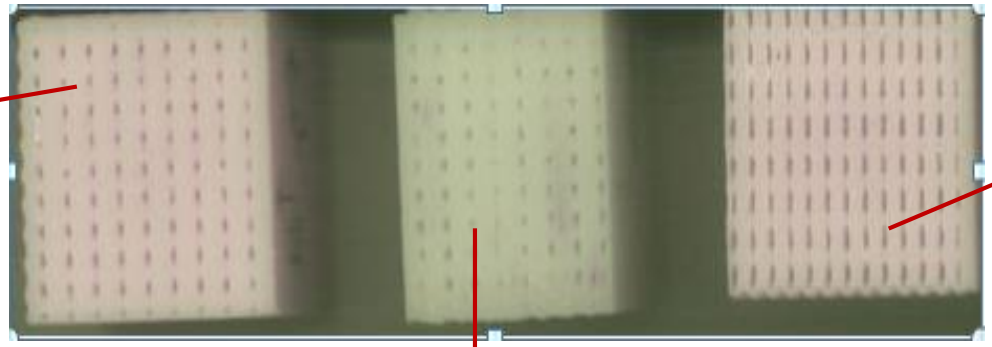
Gaps should be supported!

# 3D CM: Heat Exchanger, Self structured manufacturing!



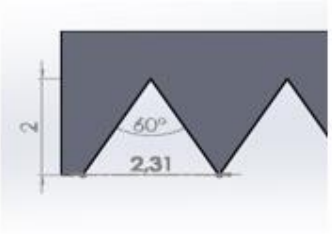



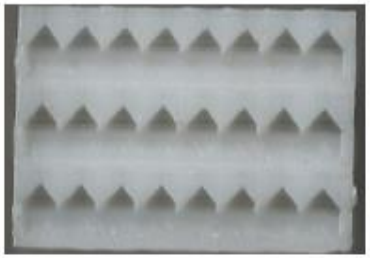
800 µm gap
260 µm layers

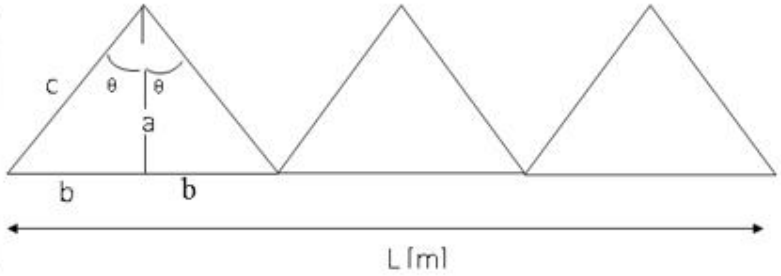
500 µm gap
260 µm layers

800 µm gap 90
µm layers

# 3D CM: Heat Exchanger, Compactness!



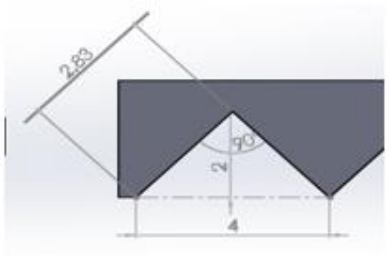


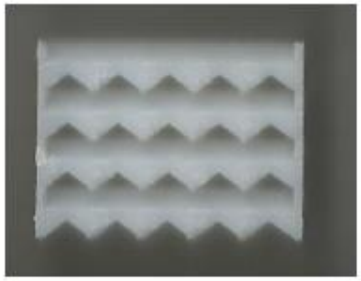

$\beta = 671.14\ m^2/m^3$ , $\sigma = 0.655$

$$L = 2xbxn$$
$$L = 2xa\tan\theta xn$$
$$2n = \frac{L}{a\tan\theta}$$

$$Total\ \text{Wall Length} = \frac{L}{\sin\theta}$$

$$\sigma = \frac{Open\ Volume}{Total\ \text{Volume}}$$

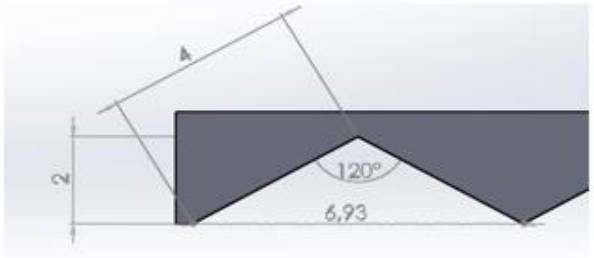


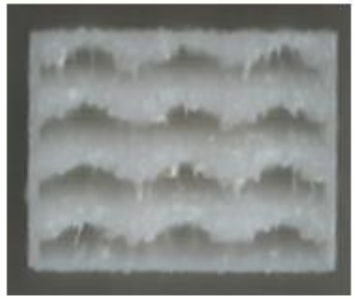



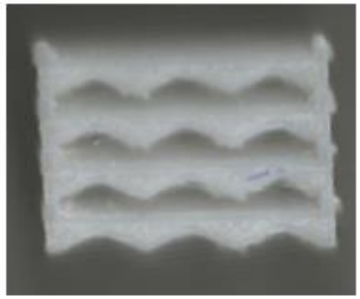
$\beta = 778.2\ m^2/m^3$ , $\sigma = 0.718$

β: Surface area density

σ: Porosity

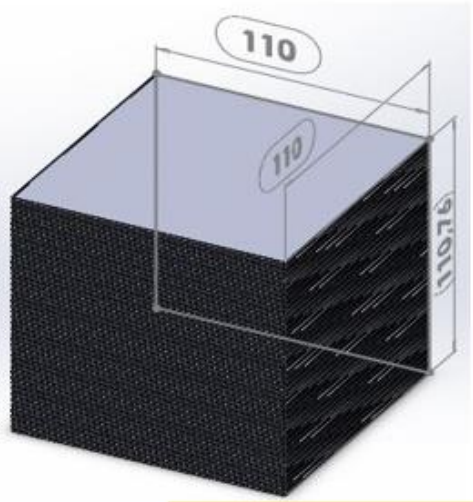


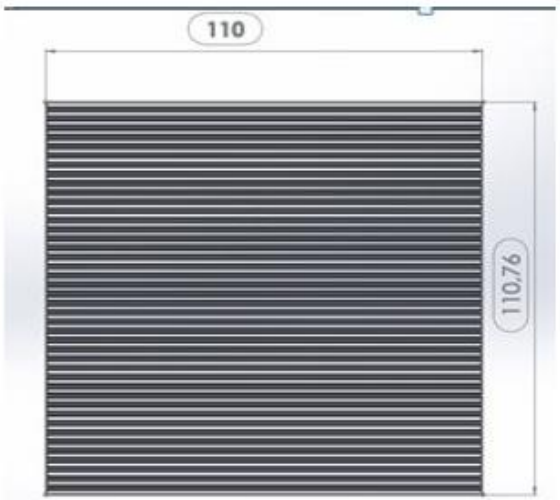





$\beta = 722.02\ m^2/m^3$ , $\sigma = 0.760$

# 3D CM: Heat Exchanger, Real size!

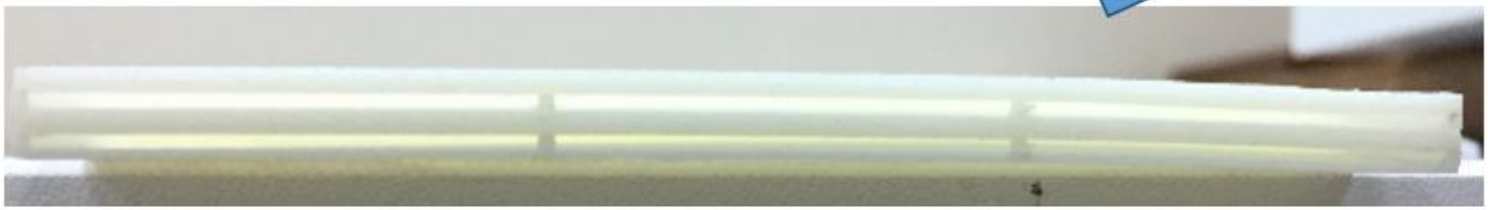


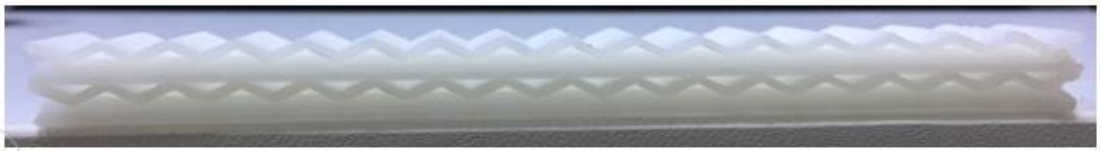





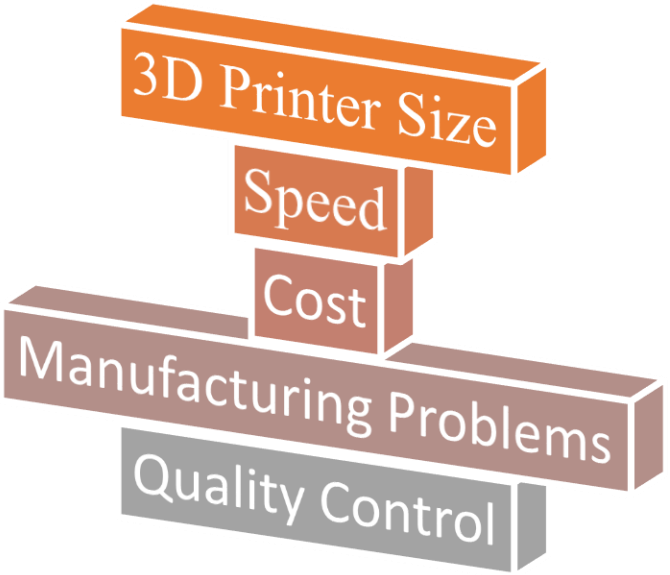
**Undulation and tear**

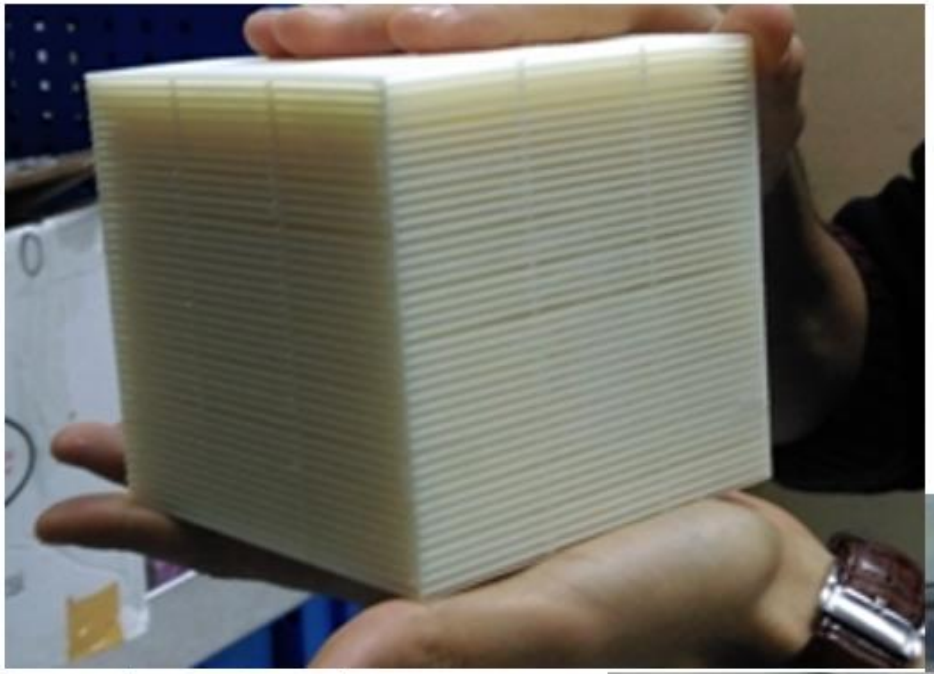
OK

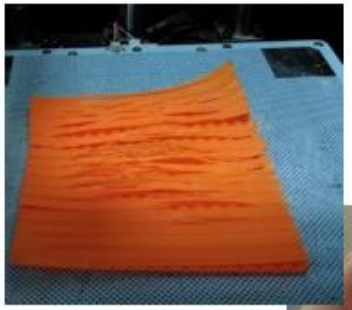


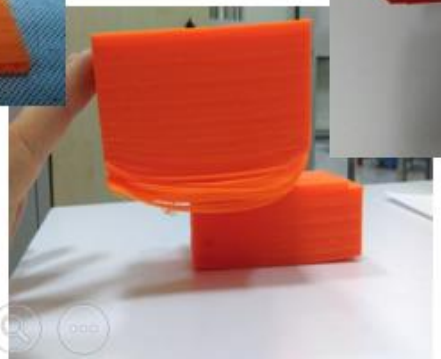


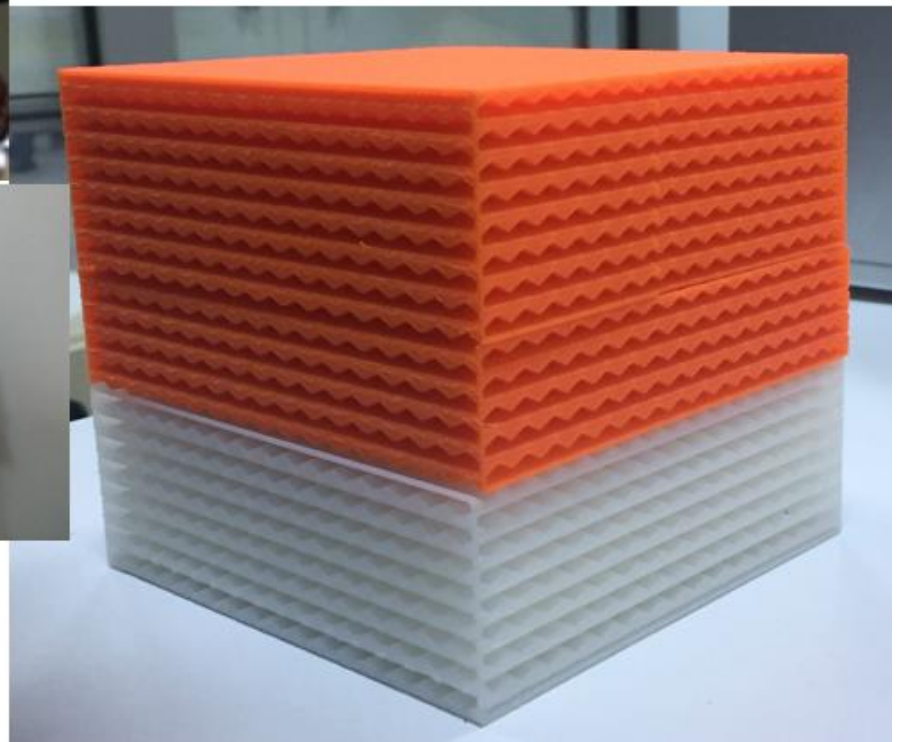
# 3D CM: Heat Exchanger, Real size!



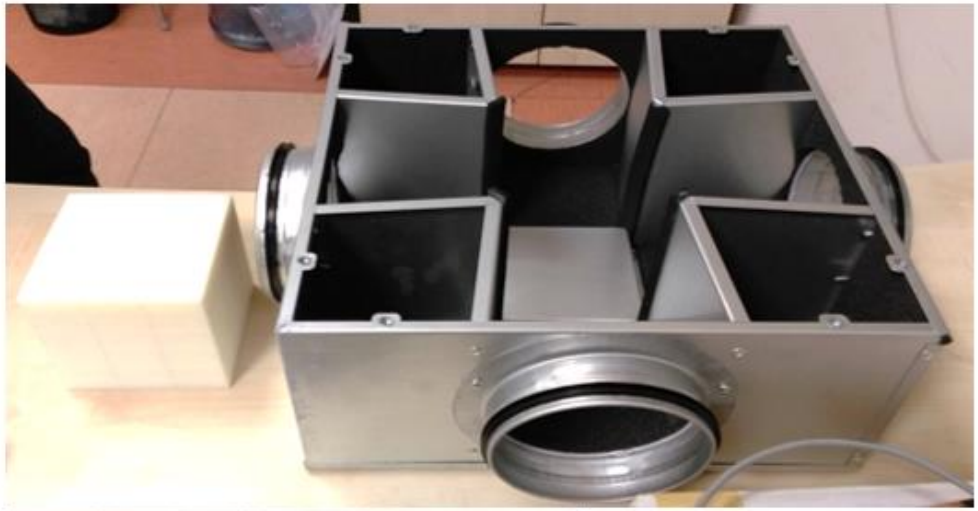



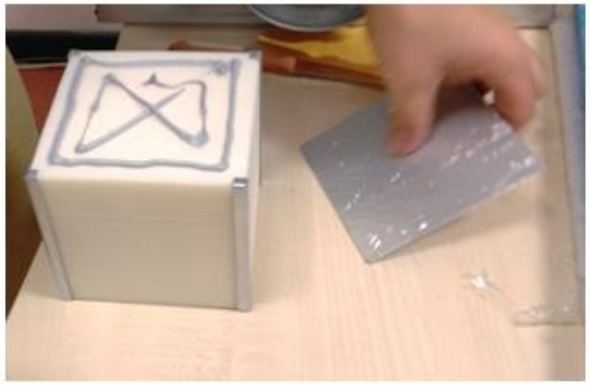


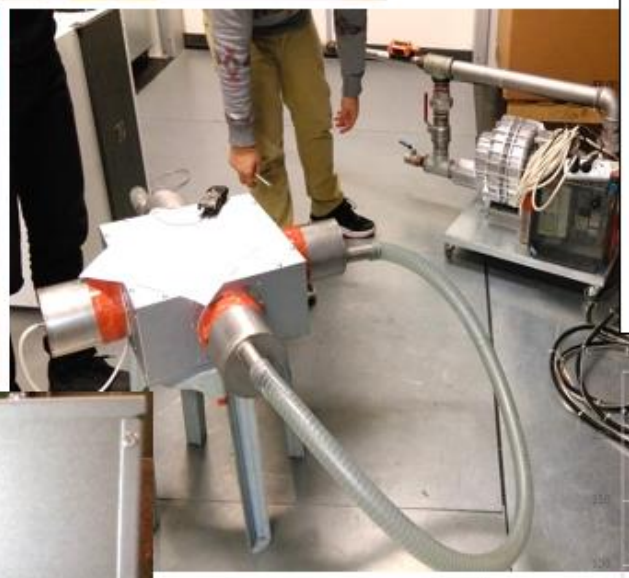




# 3D CM: Heat Exchanger, Tests





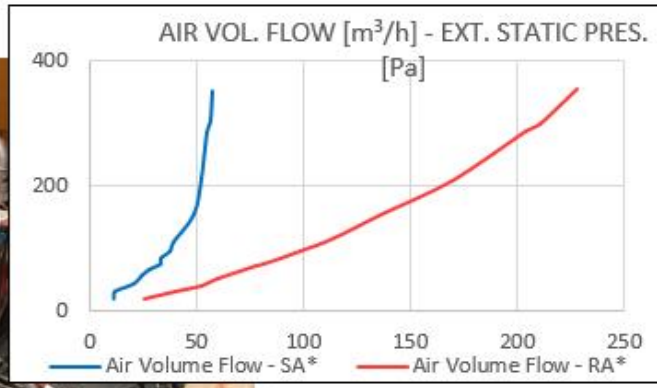


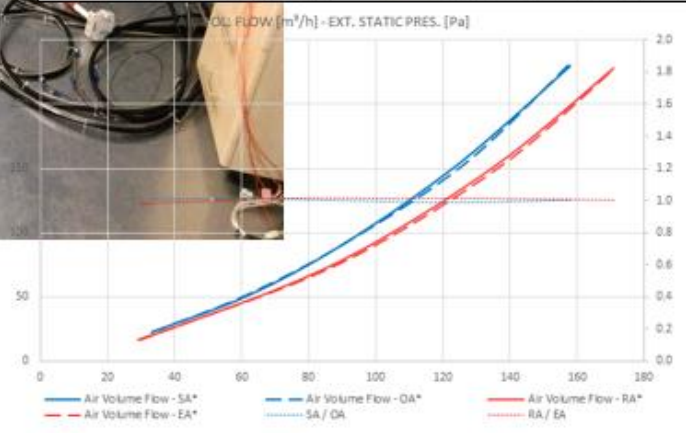
EN 308

Pressure drop

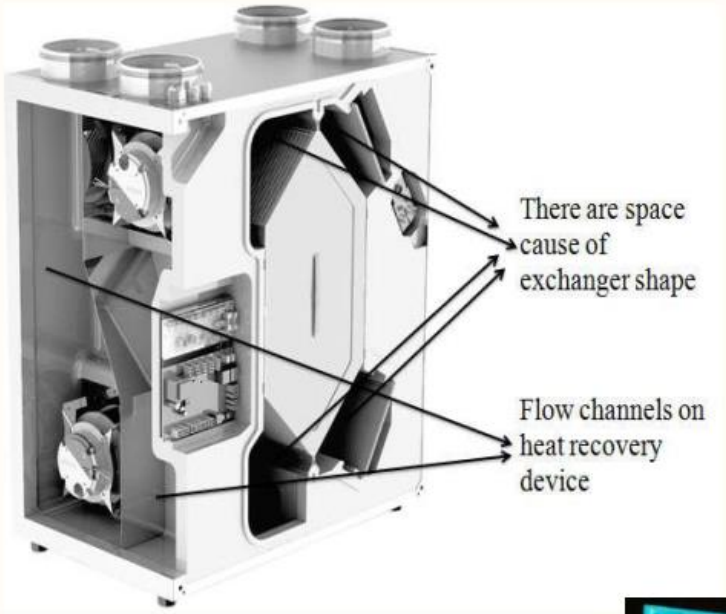
Thermal Efficiency

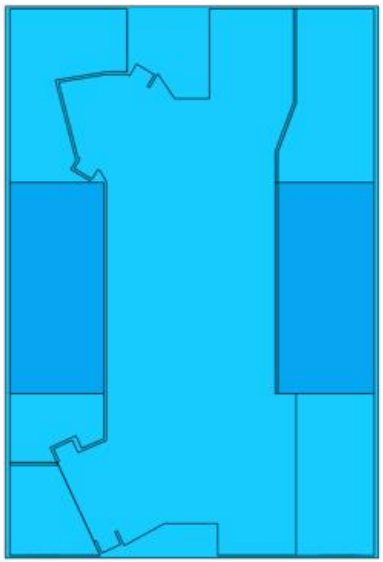
Leakage

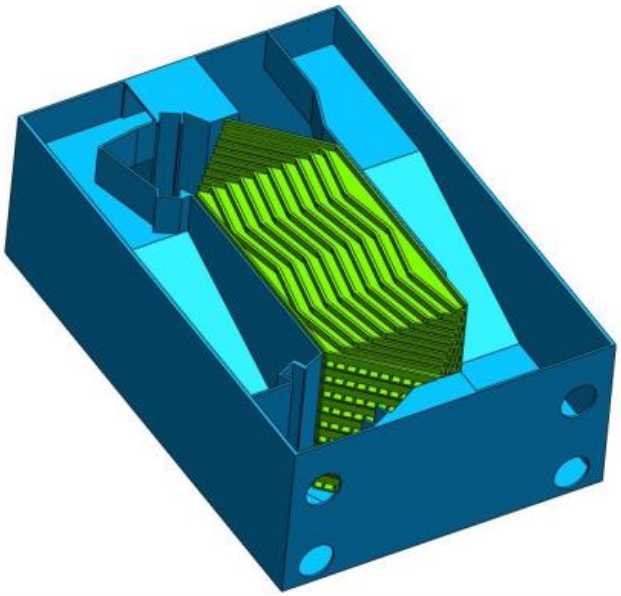


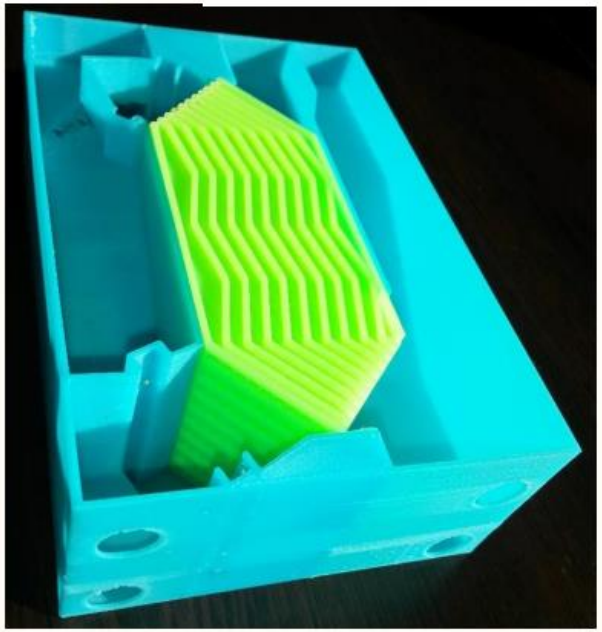



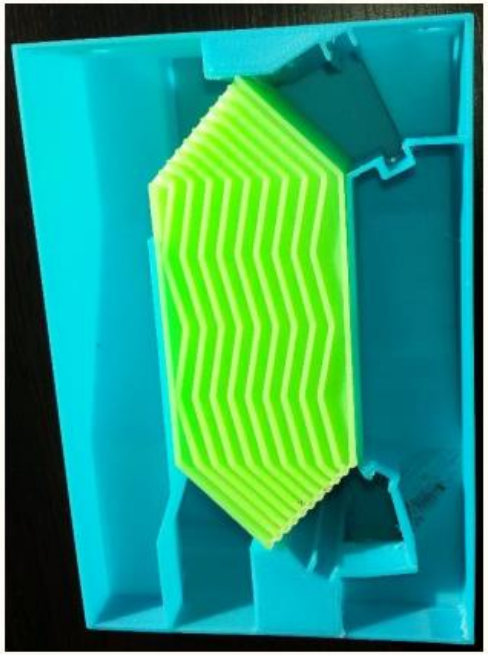
# 3D EM: Equipment Manufacturing



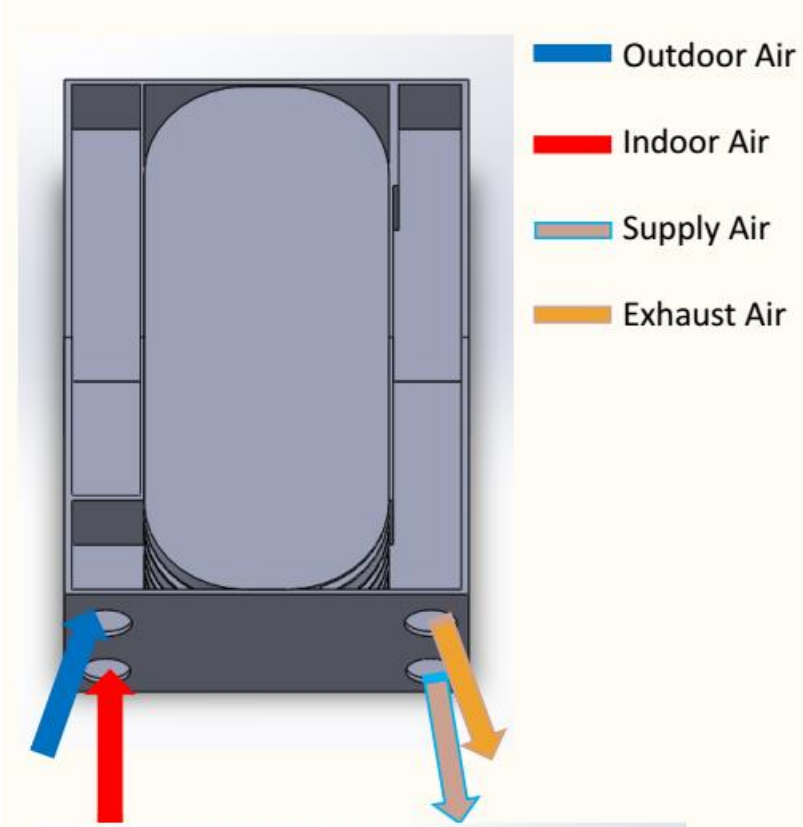



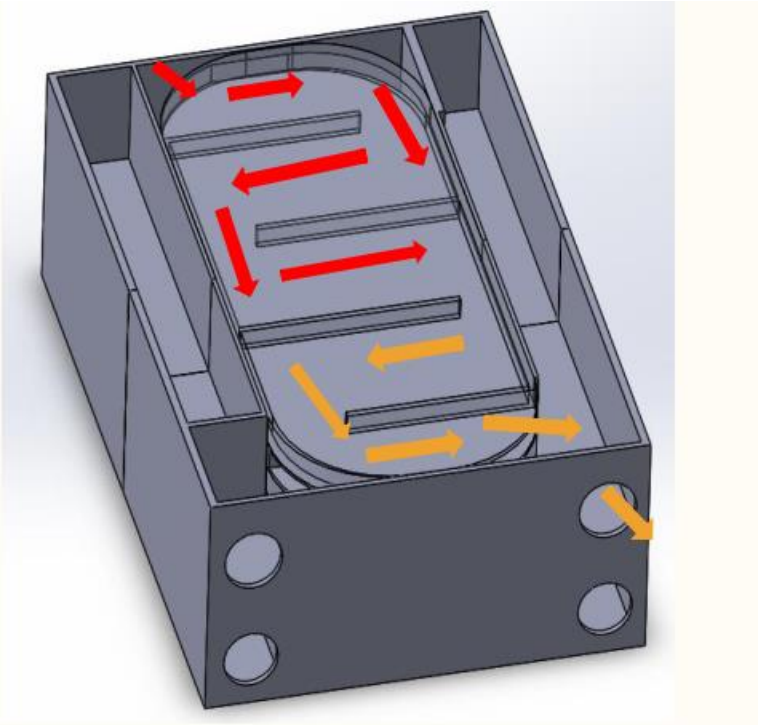


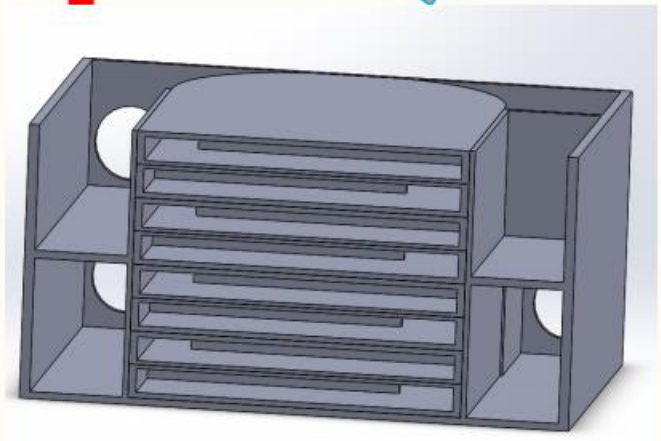


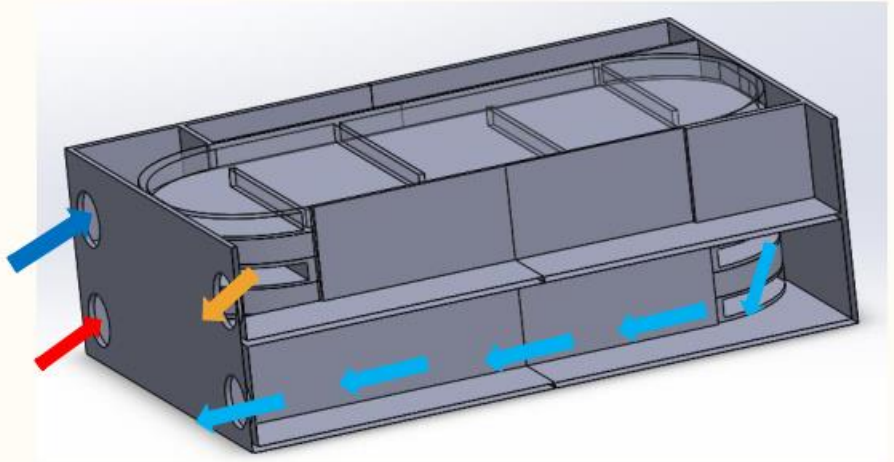


# 3D EM: Equipment Manufacturing

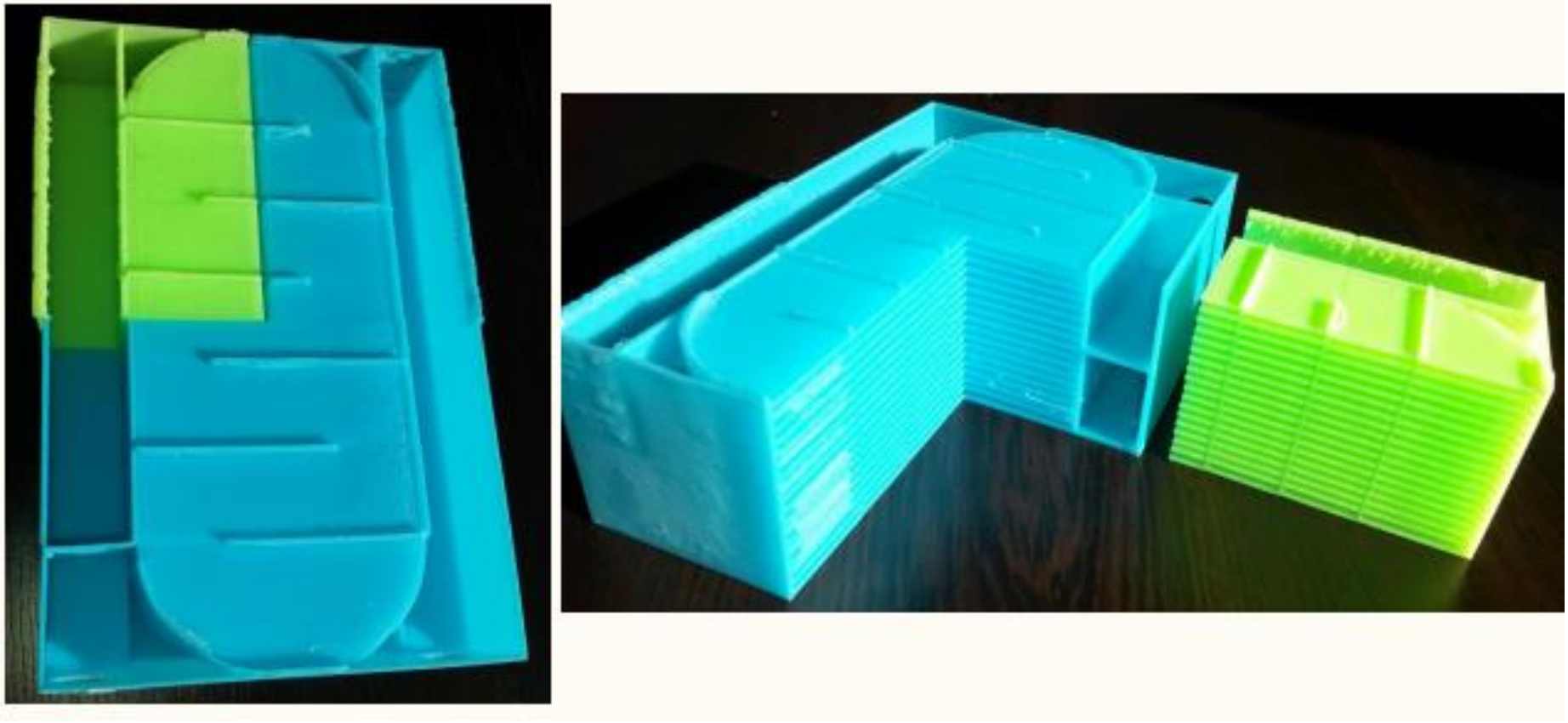


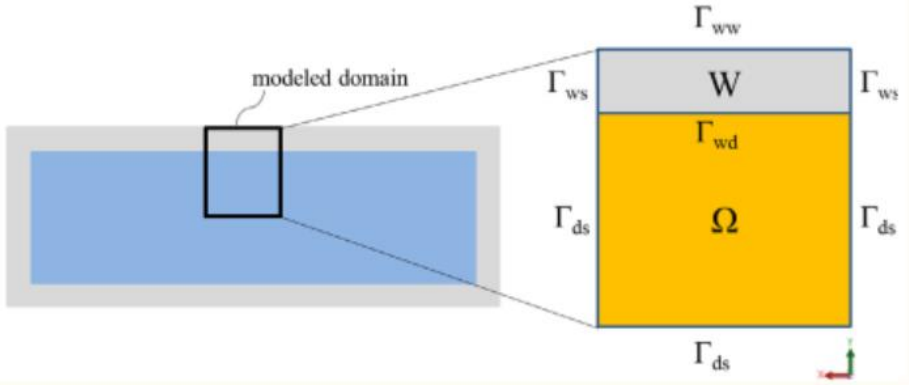


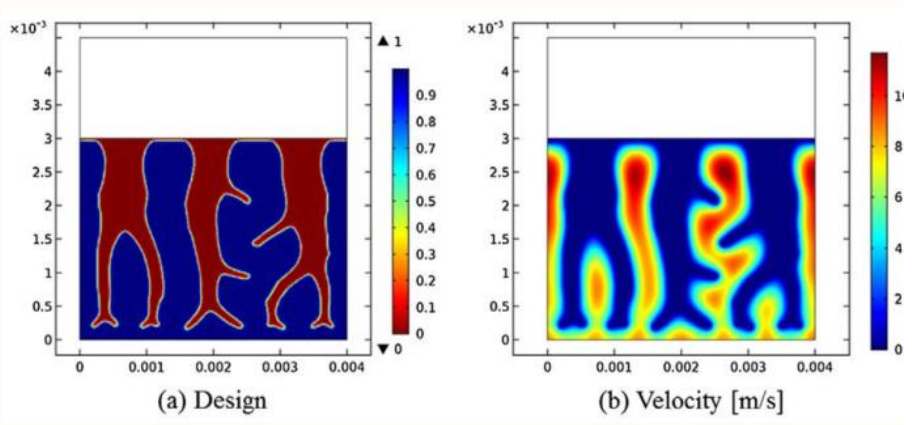


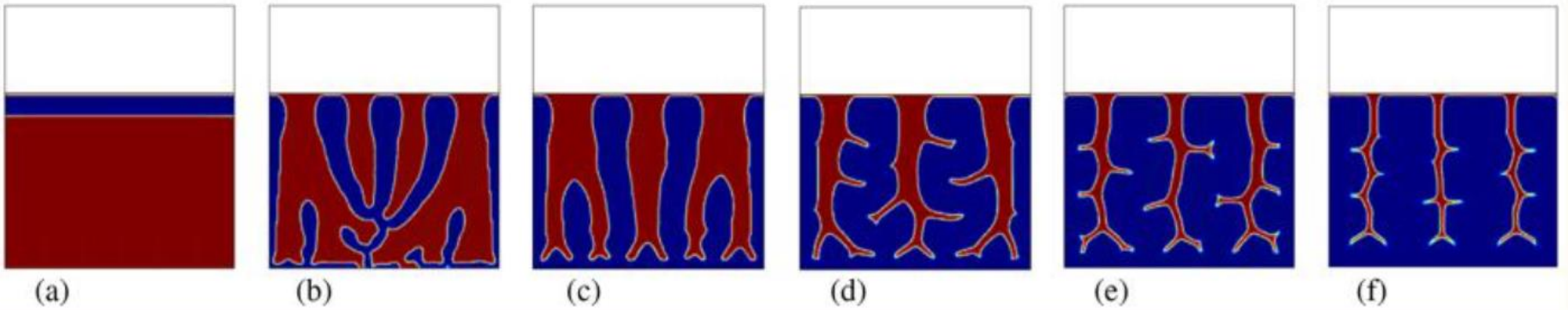
# 3D EM: Equipment Manufacturing



# March 10th 2017




Research Paper

Applied Thermal Engineering 119 (2017) 10–24

## A fully developed flow thermofluid model for topology optimization of 3D-printed air-cooled heat exchangers

Jan H.K. Haertel [a,*], Gregory F. Nellis [b]

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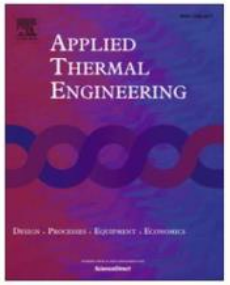
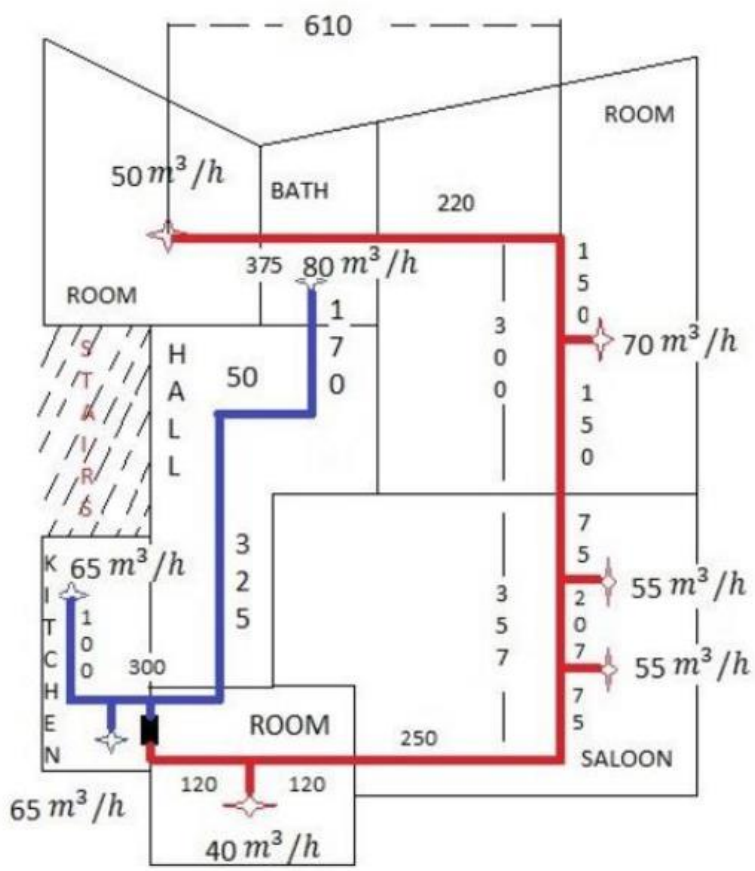
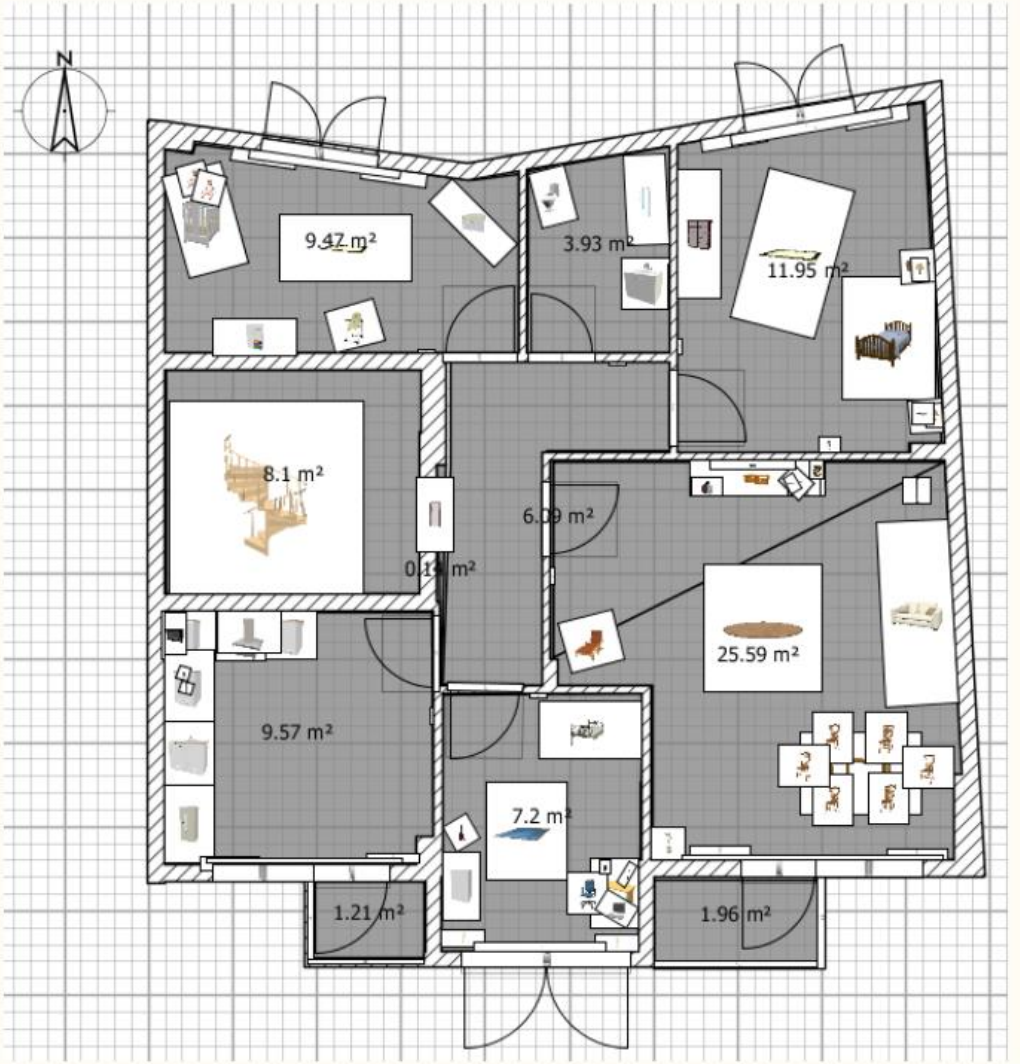
[b] Department of Mechanical Engineering, University of Wisconsin–Madison, 1500 Engineering Drive, Madison, WI 53706, USA

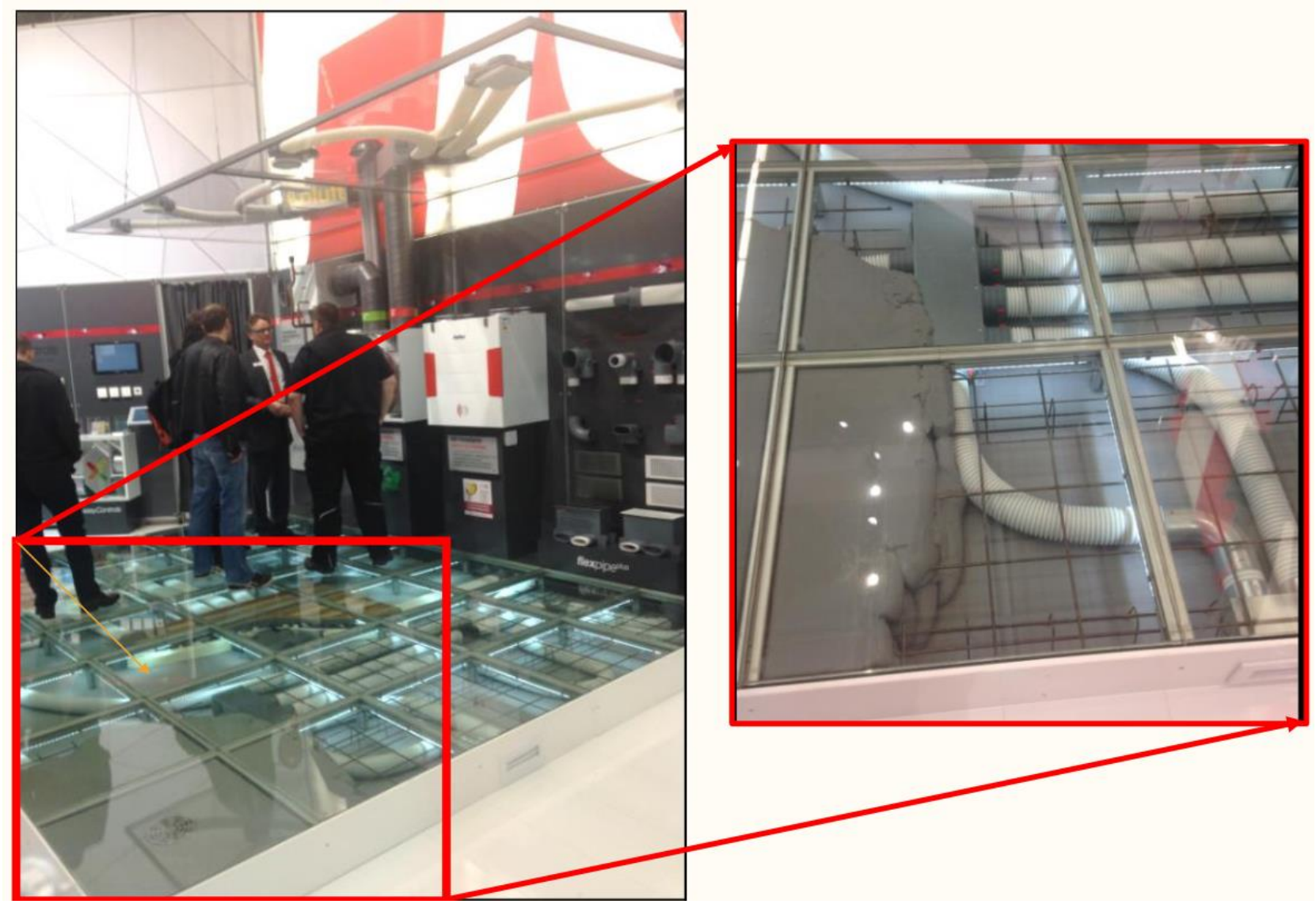


# 3D EM: Building Construction

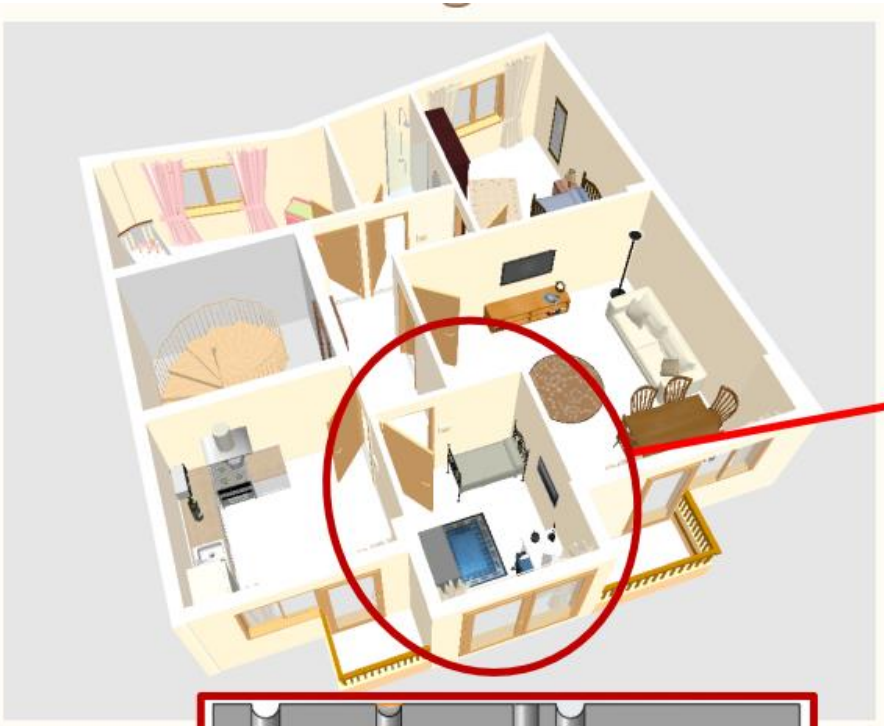


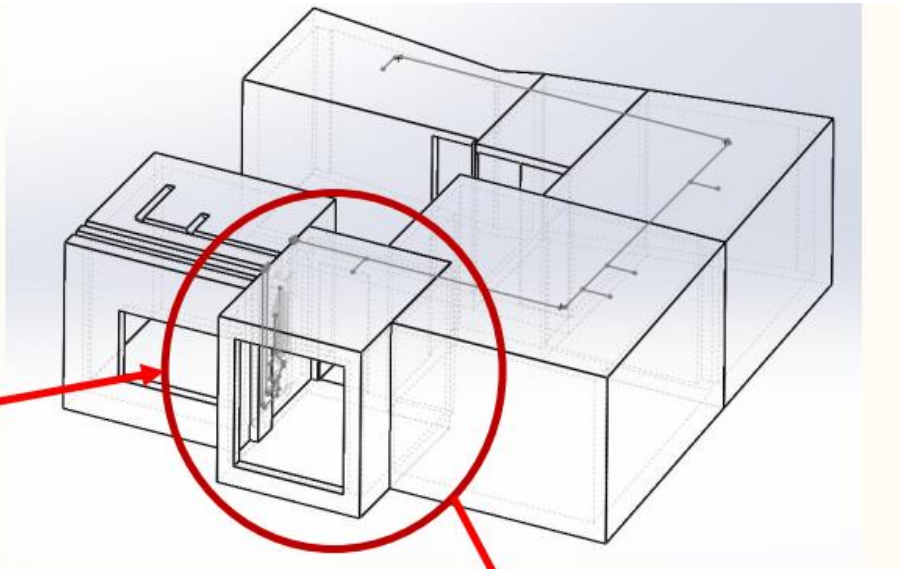



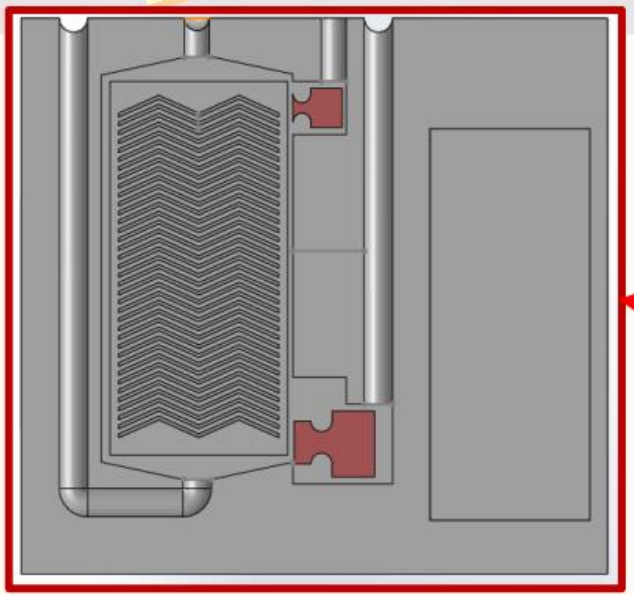
# 3D EM: Building Construction

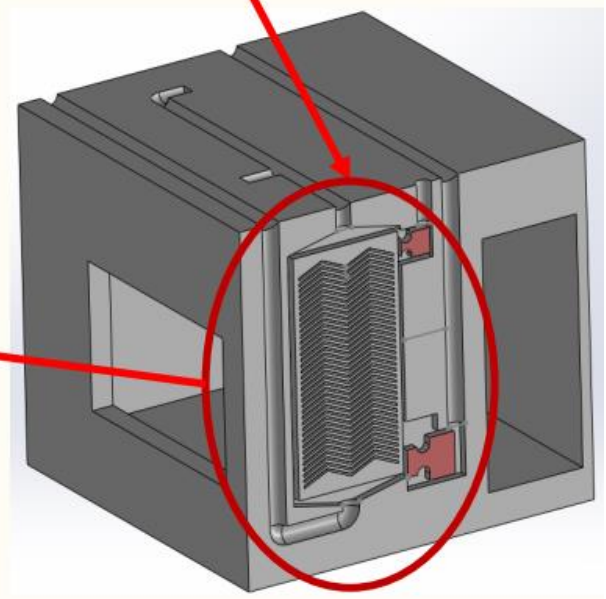


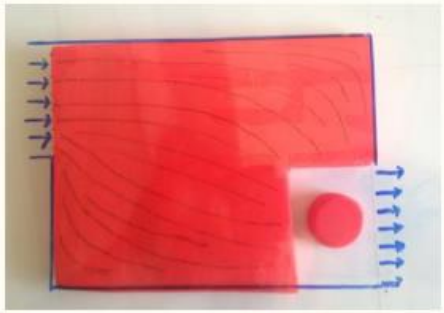
# 3D EM: Building Construction

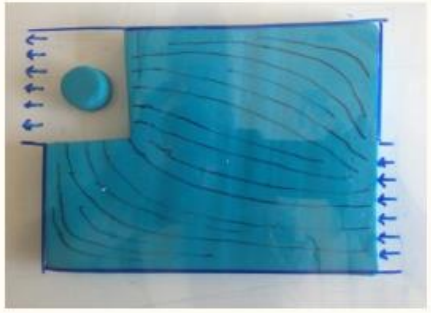


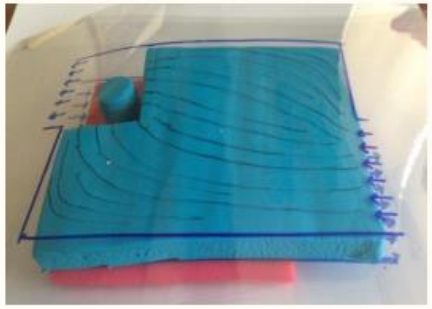








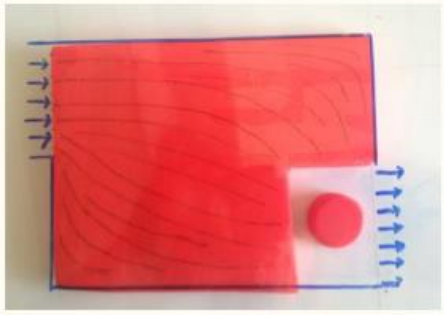


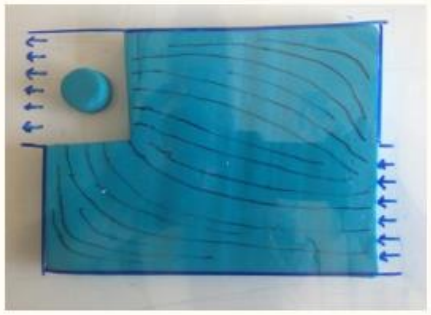


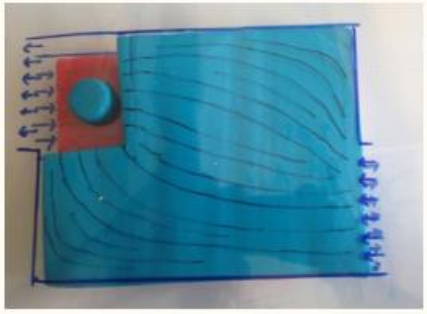
# Conclusion

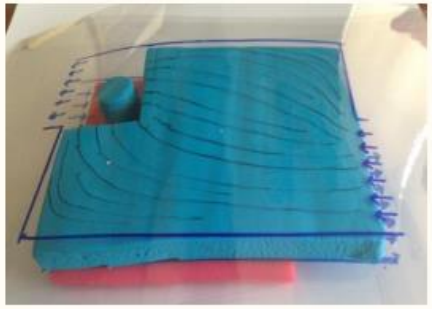
## Our Perspective:

1. Additive manufacturing will be an **alternative tool** for manufacturing firstly the HVAC components, then the units (HRVU, AHU, etc ) **in the near future**.





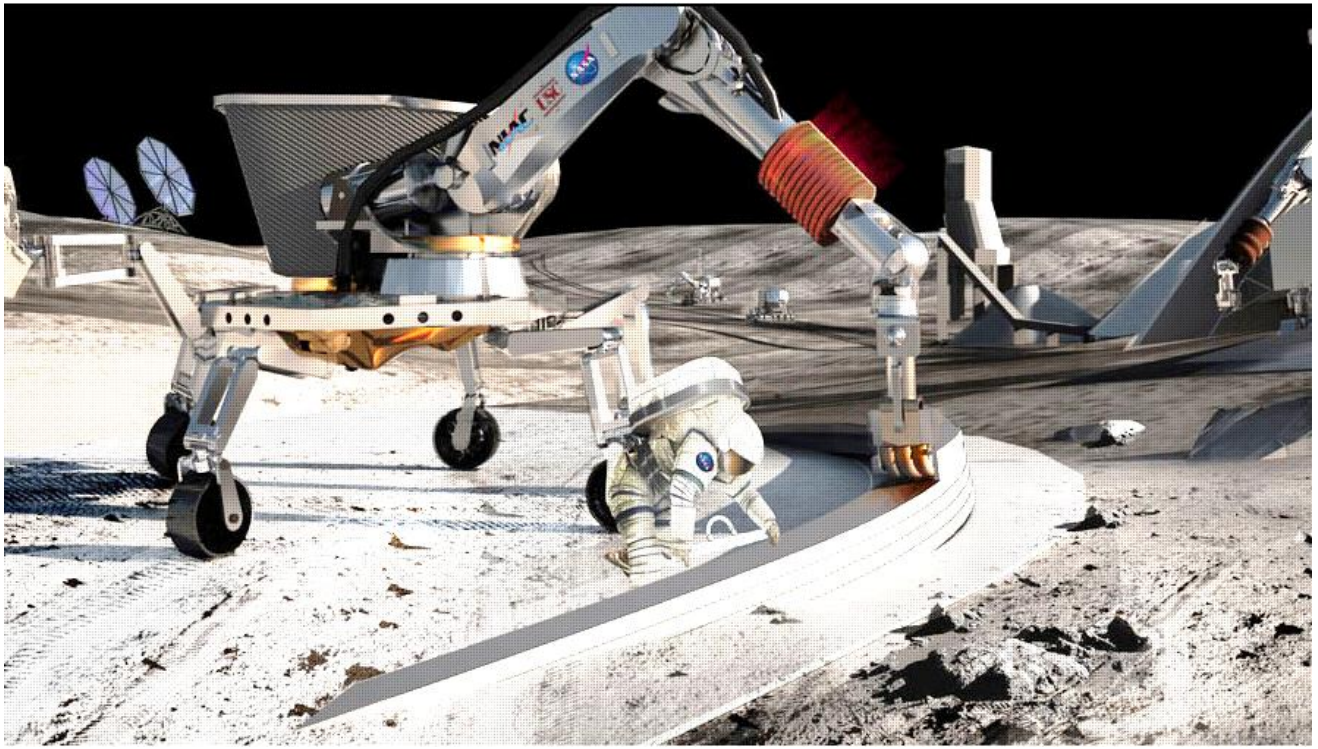


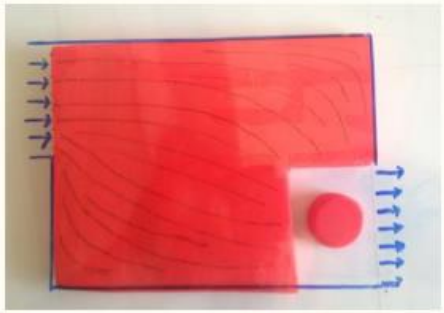


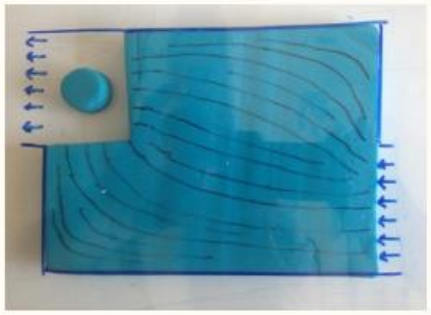
# Conclusion

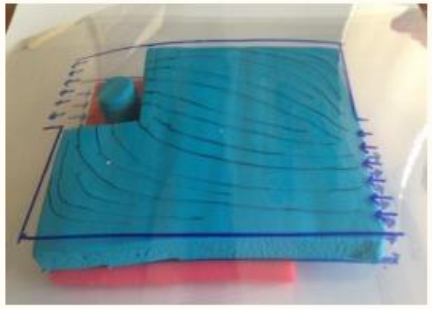
## Our Perspective:

2. The days that additive manufacturing will be used for **production of all of the components** (walls, roof, ducts) of a building on site in an holistic approch is **not so far**.





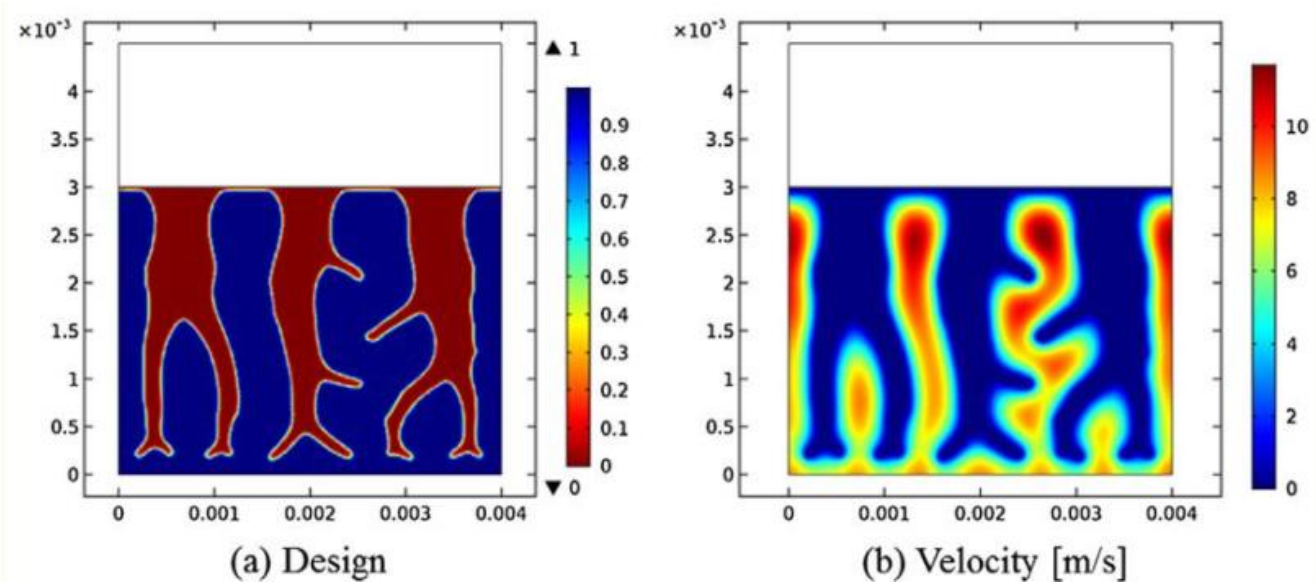


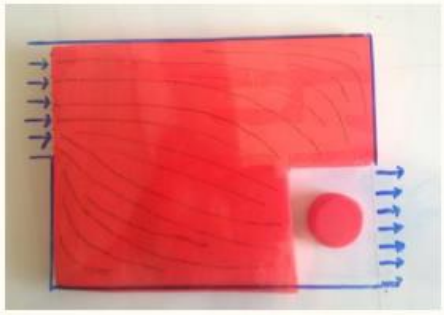


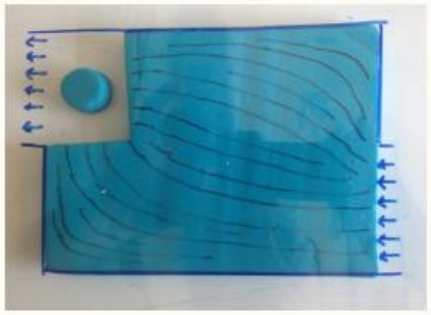
# Conclusion

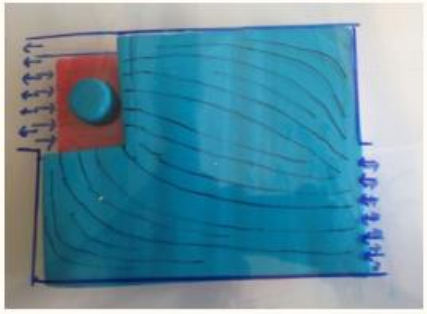
## Our Perspective:

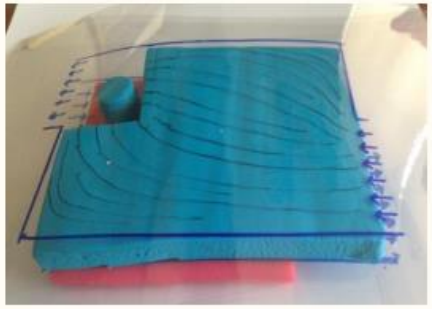
3. Additive manufacturing will change the World from cartesian design to non-cartesian (freeform, nonlinear). This will anable more compact unit designs with higher performance while keeping the capacity the same .







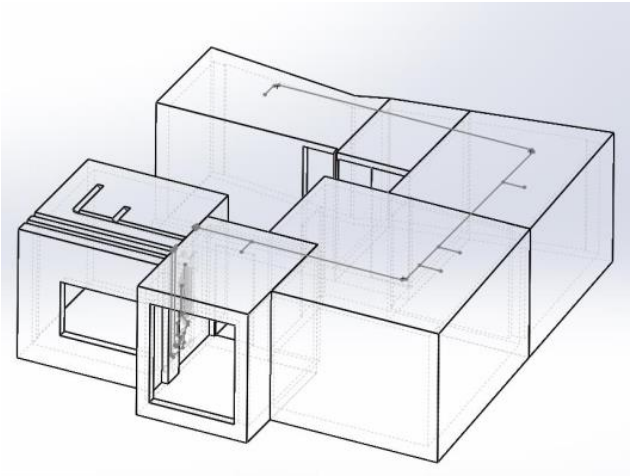


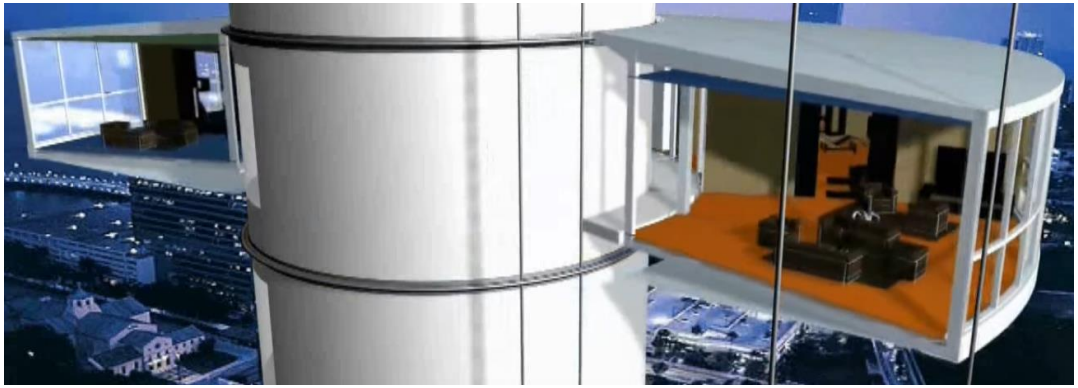


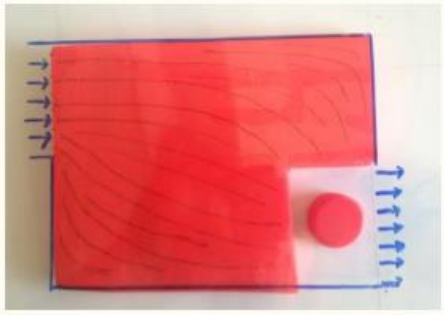
# Conclusion

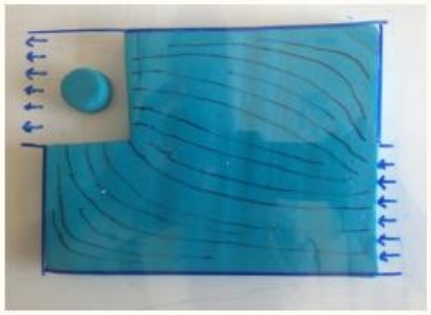
## Our Perspective:

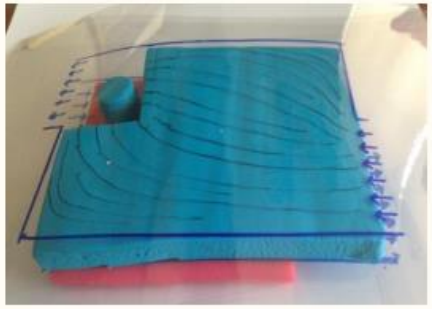
4. Additive manufacturing will **enforce** designers of **different diciplines** to cooperate for integrated design.







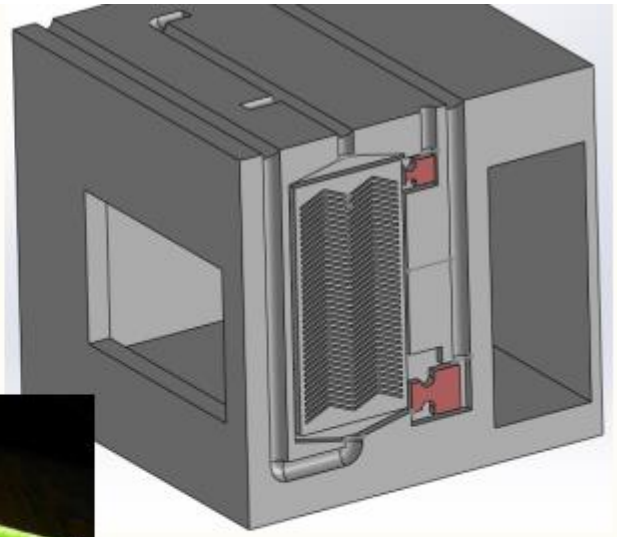


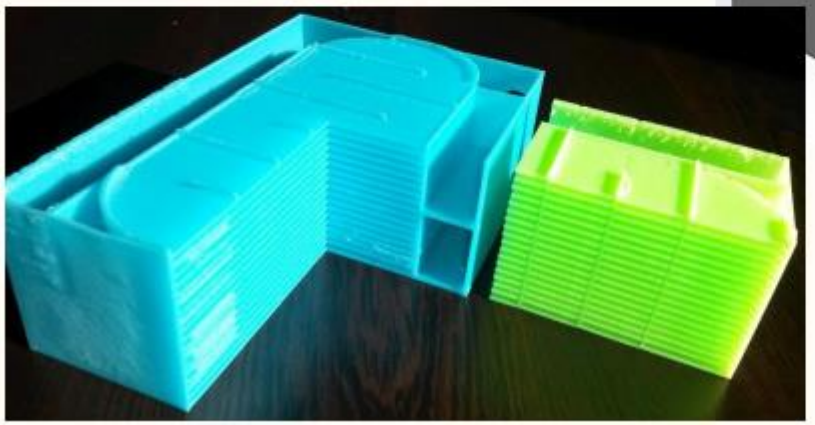


# Conclusion

## Our Perspective:

5. Integrated building design for additive manufacturing will arise a new sector that will be developing softwares for 3D printed components designed for both cartesian and non-cartesian geometries.





# The team

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**Z. Haktan Karadeniz**
**Macit Toksoy**


# Thank you for your Attention.

# Questions ??

# Questions ?

“When it comes to change, we tend to ‘hang on’ to what feels safe as long as possible,”

“When we can’t see the future, we don’t know how far we will fall. That can be frightening. We must work to shape tomorrow, so we feel empowered to ‘let go.’”

Timothy Wentz
ASHRAE 2016-17 President