ADDOPTML Midterm Meeting - Training, Transfer of Knowledge & Networking

NIKOS D. LAGAROS

Layout

Introduction by the Coordinator

❑ Secondments implementation vs Gantt chart planning

❑ Secondments - new knowledge acquisition, training activities, new soft skills acquisition and career

development opportunities

❑ Built-in return mechanism (return phase) for knowledge sharing and long-term collaboration

❑ Events organized within the network and beyond

Layout of the WPs

Work Package No	Work Package Title	Activity Type	Number of person-months involved per secondment	Lead Beneficiary	Start Month	End month
1	Development of topology-sizing design optimization methodology incorporating nonlinear FEM analyses and machine learning	Research and Innovation	80	1	1	24
2	Determination of material constitutive relations for 3D printed metal and concrete specimens, using also recycled consumables, by means of tests and machine learning	Research and Innovation	59	2	1	36
3	Development of the ADDOPTML optimization and machine learning aided additive manufacturing framework, application to characteristic case studies and experimental verification	Research and Innovation	90	3	13	48
4	Application of the ADDOPTML framework to the generative design concept	Research and Innovation	28	3	25	48
5	3D printed optimized metal deployable structures to address humanitarian crises	Research and Innovation	82	1	13	48
6	3D printed optimized concrete human shelter structure for post-disaster housing	Research and Innovation	62	7	13	48
7	Space applications of the ADDOPTML framework	Research and Innovation	29	6	25	48
8	Diploma theses, seminars/workshops and an international conference on 3D printed optimized structures - Communication, dissemination and exploitation activities	Training, Communication and Dissemination	72	1	1	48
9	Management and coordination	Management	22	1	1	48

TOTAL: 524 PM

Secondments per participant

Partner number	Partner short name	Country	EU/AC or TC	Academic sector	Total Number of secondments	Total Researcher Months Period 1	Total Researcher Months Period 2	Total Researcher Months Overall	Total Researcher Months (%)
1	NTUA	Greece	EU/AC	Yes	15	60.00	96.00	156.00	29.77%
2	POLITO	Italy	EU/AC	Yes	7	22.00	18.00	40.00	7.63%
3	UCY	Cyprus	EU/AC	Yes	8	4.00	12.00	16.00	3.05%
4	USTUTT	Germany	EU/AC	Yes	4	0.00	10.00	10.00	1.91%
5	IDEA75	Italy	EU/AC	No	3	5.00	6.00	11.00	2.10%
6	SPACEAPPS	Belgium	EU/AC	No	1	0.00	5.00	5.00	0.95%
7	IDONIAL	Spain	EU/AC	Yes	4	6.00	4.00	10.00	1.91%
8	EWF	Belgium	EU/AC	No	7	2.00	8.00	10.00	1.91%
9	MX3D BV	Netherlands	EU/AC	No	5	2.00	8.00	10.00	1.91%
10	S&S	Greece	EU/AC	No	9	12.00	38.00	50.00	9.54%
11	RISA	Germany	EU/AC	No	7	22.00	28.00	50.00	9.54%
12	VUB	Belgium	EU/AC	Yes	7	16.00	4.00	20.00	3.82%
13	INFERSENCE	Greece	EU/AC	No	8	24.00	26.00	50.00	9.54%
14	JUST	Jordan	TC	Yes	9	41.00	45.00	86.00	16.41%
	TOTAL				**94**	**216.00**	**308.00**	**524.00**	**100.00%**

Secondments status

Name	Finished		In progress		Total	
	Number	Months	Number	Months	Number	Months
NTUA	1	6	5	54	6	60
POLITO	0	0	4	22	4	22
IDEA75	0	0	1	5	1	5
S&S	0	0	1	6	1	6
RISA	2	16	0	0	2	16
VUB	2	3	1	8	3	11
INFERSENCE	0	0	2	24	2	24
JUST	2	24	2	17	4	41
all	7	49	16	136	23	185

Name	Finished		In progress		Total	
	Number	Months	Number	Months	Number	Months
NTUA	7	41.6	3	23	10	64.6
POLITO	0	0	2	10.1	2	10.1
IDEA75	0	0	1	5	1	5
S&S	1	6	1	12	2	18
RISA	2	5.7	0	0	2	5.7
INFERSENCE	0	0	2	12	2	12
JUST	4	18	8	33	12	51
all	14	71.2	17	95.1	31	166.3

PLANNED
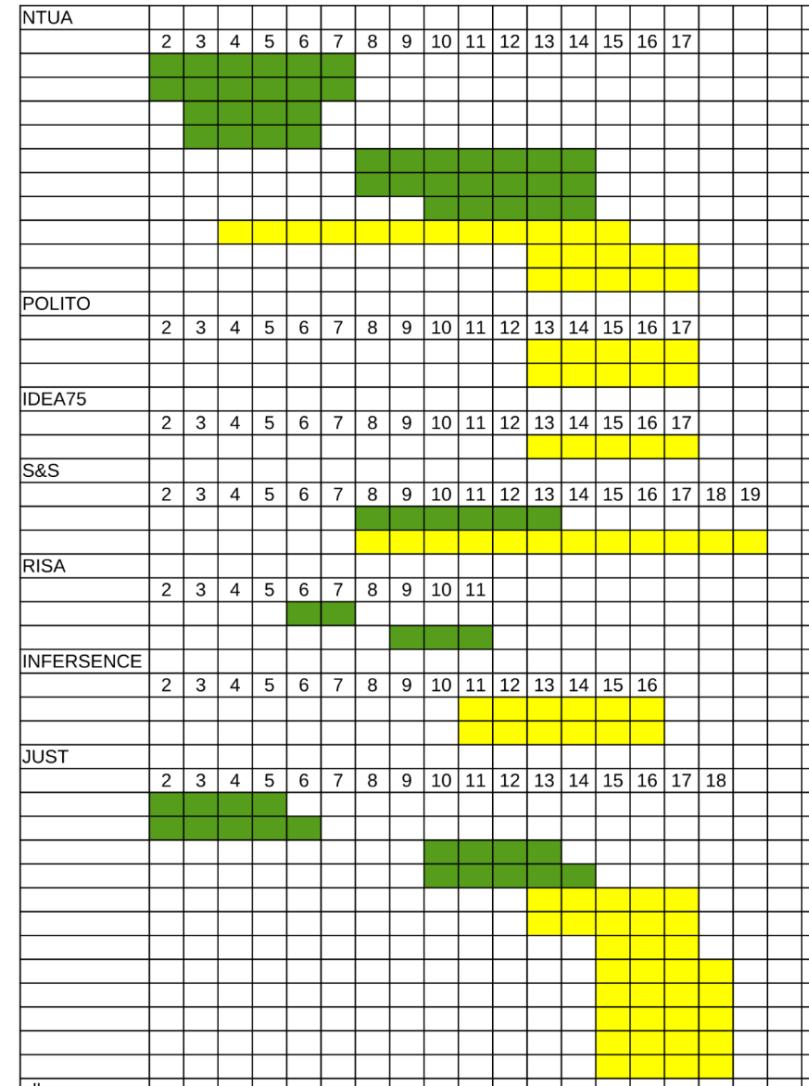
Finished: before 07/2022
In progress: months implemented before 07/2022 + months under implementation
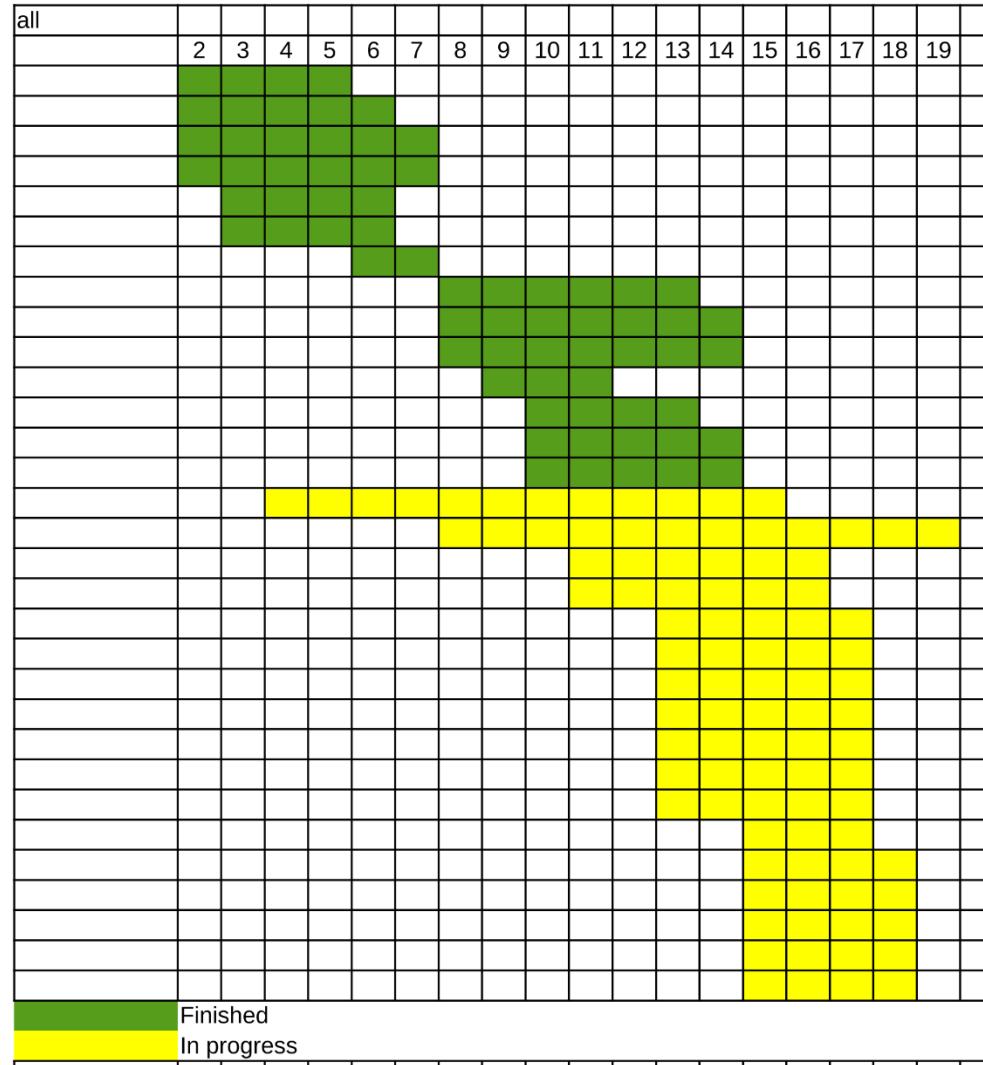
IMPLEMENTED

! more secondments are about to start

Secondments status – per beneficiary/partner

Secondments status - consortium

Secondments implementation vs Gantt chart planning

❑ More than 90 months of secondments have been performed during the 1st year instead of the 36 initially planned for.

Work Package	Secondment Months	Routes
WP1	47	NTUA to IDEA75,
		JUST to NTUA
		RISA to NTUA
		S&S to UCU
WP2	42	JUST to NTUA
		S&S to UCY
		InferSence to UCY
WP6	10	NTUA to RISA
WP8	16	NTUA to IDEA75

Secondments - new knowledge acquisition, training activities, new soft skills acquisition and career development opportunities

- **Enhanced future career prospects** of the staff members, especially younger ones:

  - solid **two-way** appreciation of the complexities involved in the European and global additive manufacturing and construction industries

  - **hands-on** experience on **cutting edge** research and technological tools providing them with research related but also **transferable skills**

  - trained by research in **state-of-the-art** additive manufacturing technologies, artificial intelligence, **mathematical optimisation processes** as well as **experimental methodologies and measurement techniques.**

  - close **interaction** of academic researchers with SMEs from **different fields**

- **New and lasting research collaborations**

- **Transfer of knowledge** between participating organisations and contribution to improving research and innovation potential at the European and global levels

Built-in return mechanism (return phase) for knowledge sharing and long-term collaboration

- Upon their return, the secondees give presentations within their local groups to brief on the outcomes of their visits and also discuss the potential for ongoing collaborations within the framework of ADDOPTML

- Although the project is within its 1st year of implementation, ideas have already emerged that target future collaborations beyond ADDOPTML. Within this context, Horizon Europe proposals have already been submitted with the objective of further consolidating the synergies between members.

- Knowledge sharing between the members of the project, the scientific community and the public at large

Contribution of beneficiaries/partners

The partners involved in the project belong to high level research organizations and the scientists in charge are leading experts in their respective scientific fields. They have an important and complementary research activity focusing on:

- Nonlinear dynamic analysis; large-scale structural and design optimization of real-world structures; solution of large nonlinear problems (Beneficiary 1-Coordinator NTUA)
- Nonlinear modelling and analysis of structures under static and dynamic loads, modelling and analysis of progressive collapse response of frame structures, structural safety and reliability, structural retrofitting of existing structures with traditional and innovative techniques and their design optimization with machine learning methods (Beneficiary 2-POLITO)
- Architectural technology, technology-driven design, structural and construction design, kinetic structures, earthquake engineering, passive structural control, seismic isolation, digital architectural design, fabrication strategies and physical prototyping, computer-aided design, computer-aided manufacturing, parametric-associative design logic and physics-based computer modelling (Beneficiary 3-UCY)
- Kinetic structures and adaptive envelope systems, integrated architectural and structural design, design methods and computational tools, motion analysis and planning, automation systems and physical prototyping (Beneficiary 4-USTUT)
- Development of industrial projects, innovative solutions in the areas of optimization, industrial automation and energy efficiency (Beneficiary 5-IDEA75)
- Research and development of innovative systems, solutions and products and also provides technology development, operation and training services to the aerospace and security markets and related industries (Beneficiary 6-SPACEAPPS)
- Development of advanced manufacturing, digitalization and materials development, including steel & metallic alloys, refractories, ceramics and raw materials, plastics and composites. Also is a specialized center in AM research and development, including 3D printing for construction application, (Beneficiary 7-FUNDACION IDONIAL)
- Updating and harmonising training and education in the field of welding (Beneficiary 8-EWF)
- Development of specialized 3D metal printing, developing ground-breaking robotic additive manufacturing technology and large-scale robotic wire arc additive manufacturing (Beneficiary 9-MX3D BV)
- Consulting engineering and structural health monitoring mainly with structural design and assessment of buildings and structures (Beneficiary 10-STRUCTURES & SENSORS)
- Development of probabilistic safety, risk and reliability analysis, mainly for nuclear energy plants, and also complex information system applications, platforms for decision analysis/support, optimisation and data analysis, including Big Data and IoT (Beneficiary 11-RISA)
- Design and analysis of transformable structures (deployable structures and kit-of-parts systems) for architectural applications (Beneficiary 12-VUB)
- Machine learning applications and optimization software, big data exploitation, data augmentation and software production (Beneficiary 13-INFERSENCE)
- Development of analysis and design of steel structures, nonlinear finite element simulations of structures, and structural optimization (Participant 1-JUST).

Events organised within the network and beyond

Meetings

- WP1 Kickoff meeting (08/07/2021) & 2nd Global meeting (02/12/2021) & 2 Progress

  meetings (19/01/2022, 07/06/2022)

- WP2   Progress meeting (16/03/2022)

- WP3   Progress meeting (18/01/2022)

- WP4, WP5, WP6, WP7   -

- WP8   Progress meeting (27/05/2022)

- WP9   Progress meeting (20/04/2022)

KICK OFF MEETING

Agenda

1. Welcome
   - Coordinator
   - Project Officer
2. Partners Presentation (5 minutes each)
   - NTUA
   - POLITO
   - UCY
   - USTUTT
   - IDEA75
   - SPACEAPPS
   - IDONIAL
   - EWF
   - MX3D
   - S&S
   - RISA
   - VUB
   - INFERSENCE
   - JUST
3. Discussions of the Coordinators day, Questions and Answers (https://ec.europa.eu/info/h2020-msca-rise-2020_en)
4. Discussion about the project implementation
   - Year 1 Staff Exchanges
   - Year 1 Deliverables
   - Financial aspects
5. Any other Business
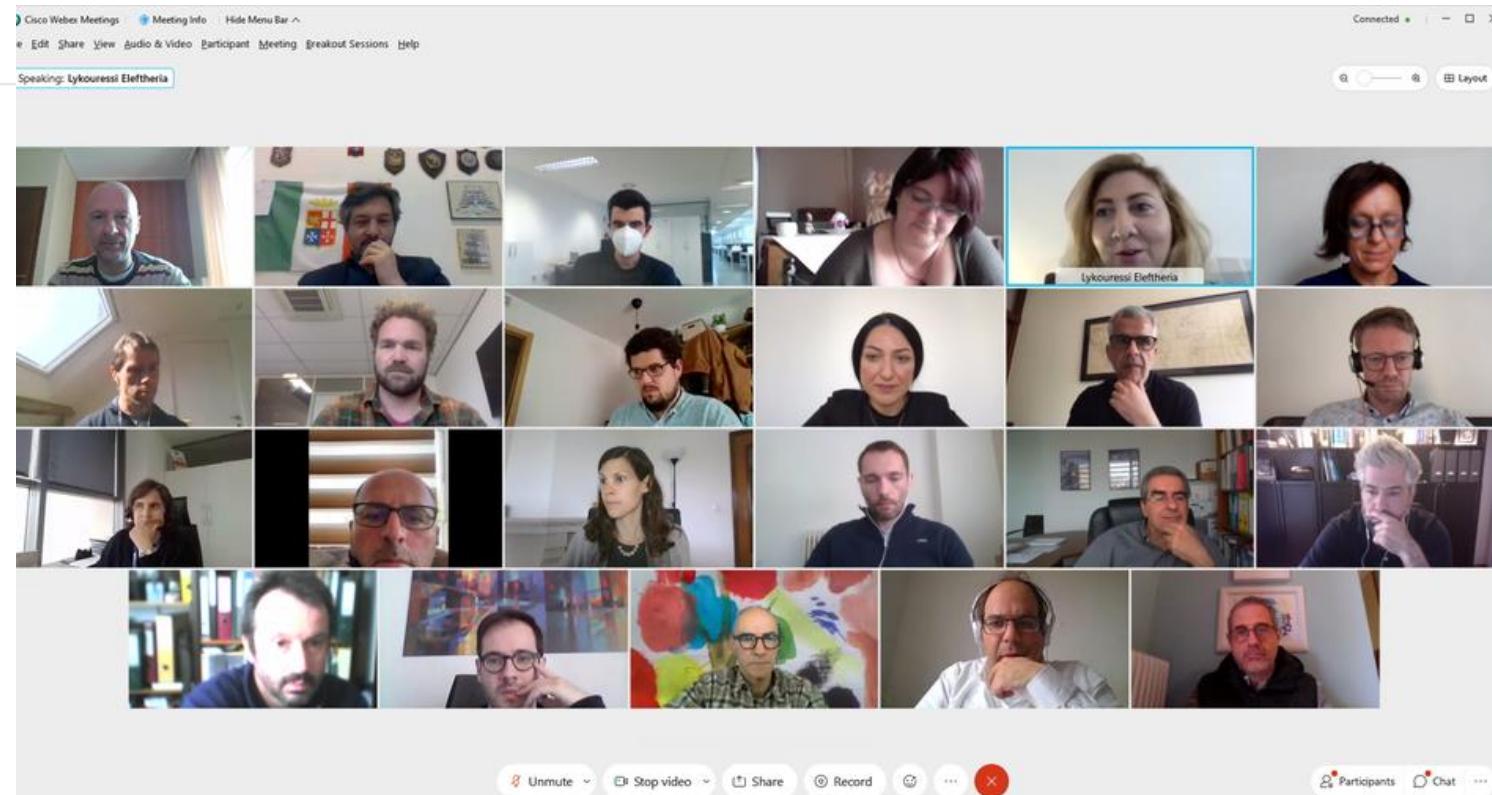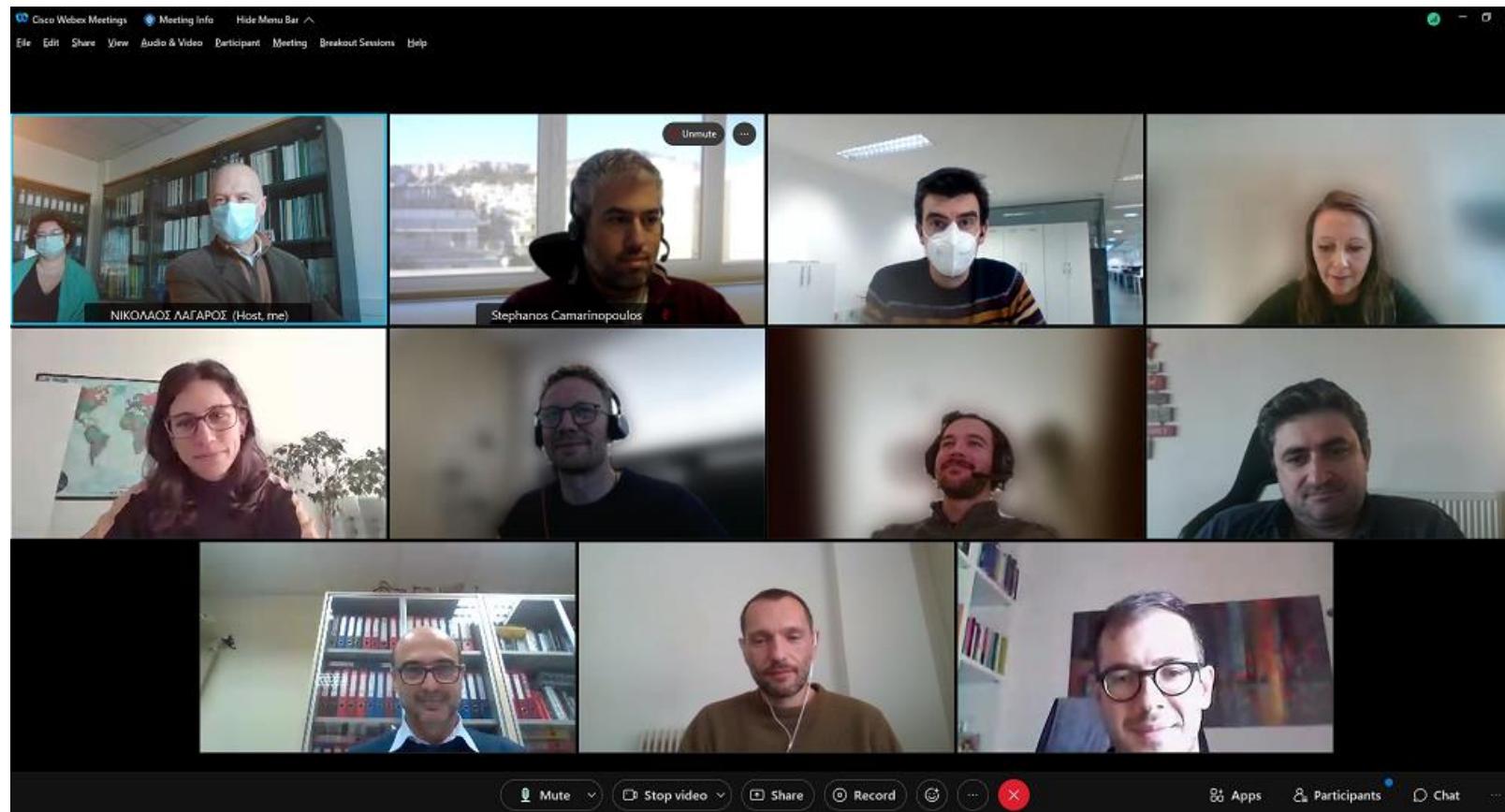
2nd GLOBAL MEETING

Events organized within the network and beyond

Network knowledge sharing events

- 18.1.2022: Seminar Presentations by IDONIAL and MX3D on advances in 3D printing technologies organized within the context of WP3

- 17.6.2022: Seminar presentation on advances in damage modelling by S. Triantafyllou within the context of WP1

Beyond the network

- 09/12/2021 to 16/12/2021: 5th International Winter School in Structural Morphology

- 27/5/2021 14:00-16:30 CET - Webinar on 3D Printing in Construction Industry. Past, Present and Future

5th International Winter School

09/12/2021 to 16/12/2021: 5th International Winter School in Structural Morphology

Agenda (pdf)

After the previous editions, the Winter School will be focused on the same main topic: the relationship between geometry and structure so called Structural Morphology. The specific focus of this edition is the study of how geometrical shape influences force flows into the structural elements for different applications. With this project, we aim to study methods, strategies and techniques recently developed employed to incrementally change assembly buildings and spaces depending on the influence of the sites strictly correlated to the culture belonging to the design location

Date: 9/12/2021, **Time:** 08:30 - 13:30 CET
Date: 16/12/2021, **Time:** 08:30 - 13:30 CET

Scientific committee:

- Giuseppe Carlo Marano, Politecnico di Torino, Dipartimento di Ingegneria Strutturale, Edile e Geotecnica
- Marco Trisciuoglio, Politecnico di Torino, Dipartimento di Architettura e Design
- Bruno Briseghella, Fuzhou University, College of Civil Engineering
- Camillo Nuti, Università degli Studi Roma Tre, Dipartimento di Architettura
- Nikos D. Lagaros, National Technical University of Athens, School of Civil Engineering
- Bao Li, Southeast University, Department of Architecture
- Lisha Ren, Tongji Universit

Organizing committee:

- Ph.D. Laura Sardone
- Dr. Chara Ch. Mitropoulou
- Eng. Raffaele Cucuzza
- Fernando Israel Leal Leyte

Webinar

27/5/2021 14:00-16:30 CET - Webinar on: 3D Printing in Construction Industry. Past, Present and Future

Agenda

The webinar will present the progress achieved so far and the challenges of the integration of 3D printing technology into the Architectural, Engineering and Construction (AEC) industry, where the developments and concerns from the Constructors, Design Offices, 3D printing technology and the Academia point of view will be presented together with a session at the end for discussion.

Invited Speakers:

- Prof. Philippe Block, Institute of Technology in Architecture at ETH Zurich
- Prof. Cristian Cremona, Technical and R&D Director, Bouygues Travaux Publics
- Gijs Van Der Velden, CEO at MX3D
- Marina Konstantatou, Specialist Modelling Group at Foster and Partner

Date: Thursday, 27th May 2021
Time: 14:00 - 16:30 CET

Organizers:

- Nikos D. Lagaros (National Technical University of Athens)
- Giuseppe Marano (Politecnico di Torino)
- Bruno Briseghella (Fuzhou University)
- Humberto Varum (Universidade do Porto)

under the auspices of ADDOPTML project, Sostratus - Association of Friends and Alumni of the School of Civil Engineering, NTUA and EU commission.
Sponsored by OptiStructure: Optimizing Structural Design
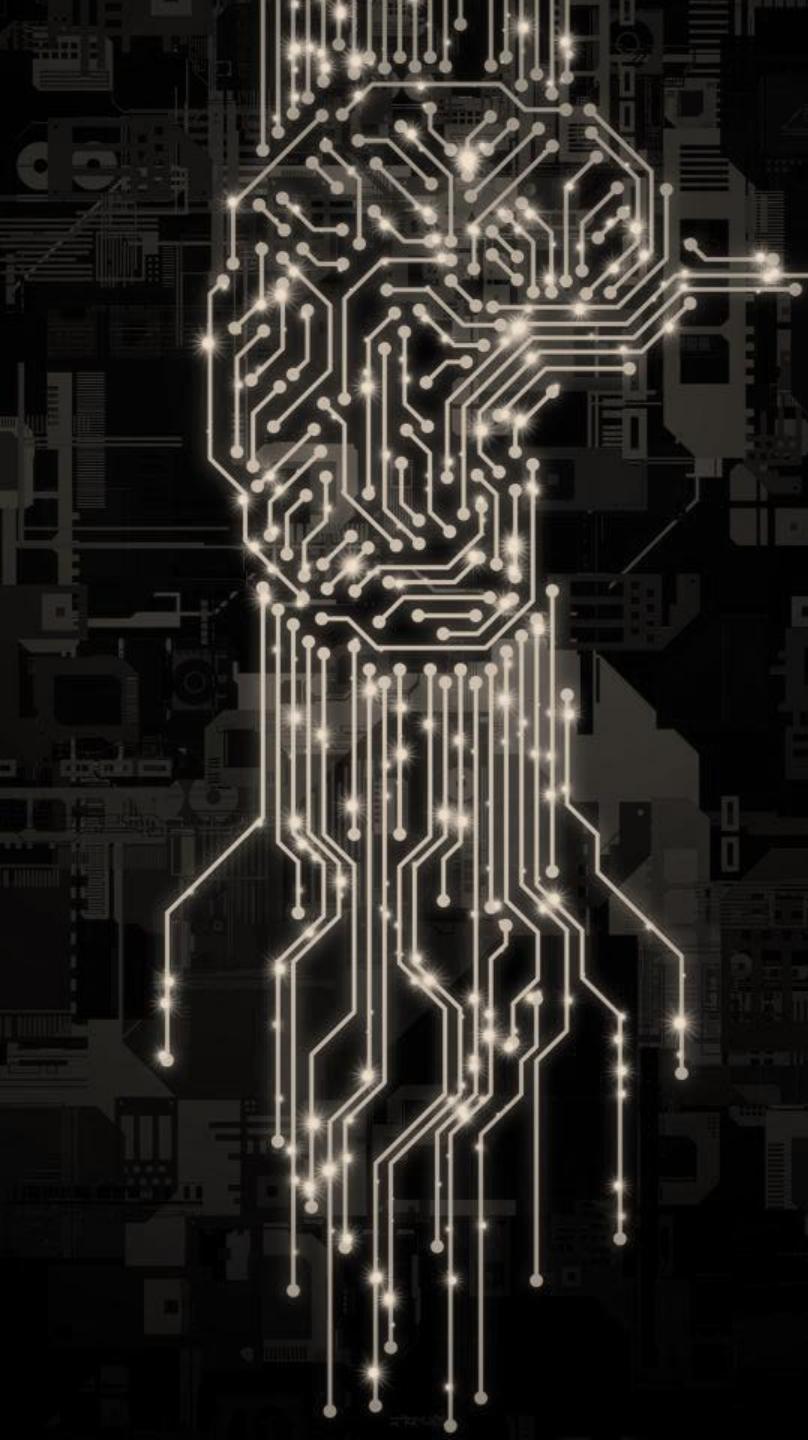
Free webinar. Event registration form here: https://bit.ly/3gMlcIP, and learn how to **participate!!**

Social Media

Do not forget

❑ 🔵 ADDOPTML Project H2020 MSCA-Rise 2020

❑ 🐦 @addoptml

❑ R^G ADDitively Manufactured OPTimized Structures by means of Machine Learning-ADDOPTML

❑ Web page: http://addoptml.ntua.gr

❑ Email: addoptml@mail.ntua.gr

ADDOPTML
Optimized 3D printed structures

ADDOPTML Midterm Meeting - Training, Transfer of Knowledge & Networking

NIKOS D. LAGAROS

ADDitively Manufactured OPTimized Structures by means of Machine Learning

Dr. Rajai Z. Al-Rousan

Jordan University of Science and Technology

Dr. Nikos D. Lagaros

National Technical University of Athens, School of Civil Engineering

Athens, 12 July 2022

Secondments

I had two secondments so far:

First one	Starting 1-9-2021 Ending 31-12-2021
Second one	Starting 15-2-2022 Ending 15-7-2022

I spent both secondments at the NTUA; working closely with the research team at NTUA lead by Dr. Nikos Lagaros.

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Optimized 3D printed structures

Athens, 12 July 2022

European Commission

Hosting

The hosting was outstanding and I really enjoyed every moment at NTUA. Dr. Nikos team at NTUA made me feel home and were generous to share and show me all research capabilities of NTUA, especially issues related to our project. They were also very generous and welcoming on the personal level.

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Athens, 12 July 2022

Collaboration Team

I collaborated with Dr. Nikos Lagaros and his research team at NTUA as well as Dr. Grantes and Dr. Triantafyllou

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Collaboration Subjects

1	I reviewed all required project tasks in general and those that we are participating in specifically: "Development of topology optimization framework incorporating non-linear FEM analyses and machine learning"
2	I also looked at the different types of 3D printed wire structures and did some literature review related to that and machine learning.

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Collaboration Subjects

3

We tried to identify what we will do once the initial stage of the project that entails optimizing and 3D printing is completed; to be ready for the nonlinear finite element simulations to confirm the behavior and identify any needed modifications.

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Outcome of Secondment

1	**We are prepared to conduct the needed FEA for the optimized 3D printed structures**
2	**We are working on some publications that are also related to the project which entails Artificial Neural Networks. We are engaging out Masters and PhD students at JUST in this regard**

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Outcome of Secondment

3

We published some publications related to the project with proper acknowledgment:

"**NLFEA of Sulfate-Damaged Circular CFT Steel Columns Confined with CFRP Composites and Subjected to Axial and Cyclic Lateral Loads**"

https://www.mdpi.com/2075-5309/12/3/296

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Next Steps

1	Continue the progress in the above steps
2	Start the simulation process
3	Publish more? Working on: **"Cyclic Behavior of Reinforced Concrete Beam-Column Joints Strengthening with FRP Composites"**

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Next Steps: "Cyclic Behavior of Reinforced Concrete Beam-Column Joints Strengthening with FRP Composites"

This paper will present the efficiency of the fiber-reinforced polymer (FRP) composites as external reinforcement in rescue the structural performance and controlling the mode of failure of the damaged reinforced concrete (RC) beam-column joint by nonlinear finite element analysis (NLFEA). Firstly, the RC beam-column model will validate against the published experimental results and then will expand to consider the effect of column axial load level (0%, 25%, 50%, and 75%) and damage level in terms of concrete compressive strength on the models with and without FRP composites

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Next Steps: "Cyclic Behavior of Reinforced Concrete Beam-Column Joints Strengthening with FRP Composites"
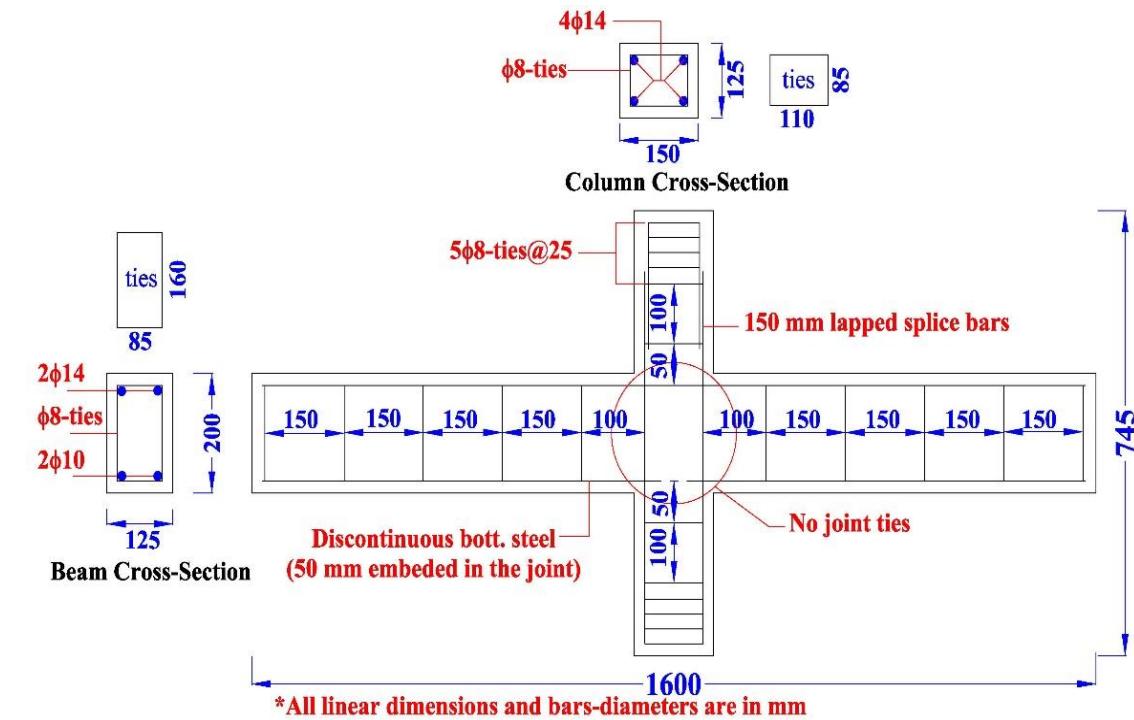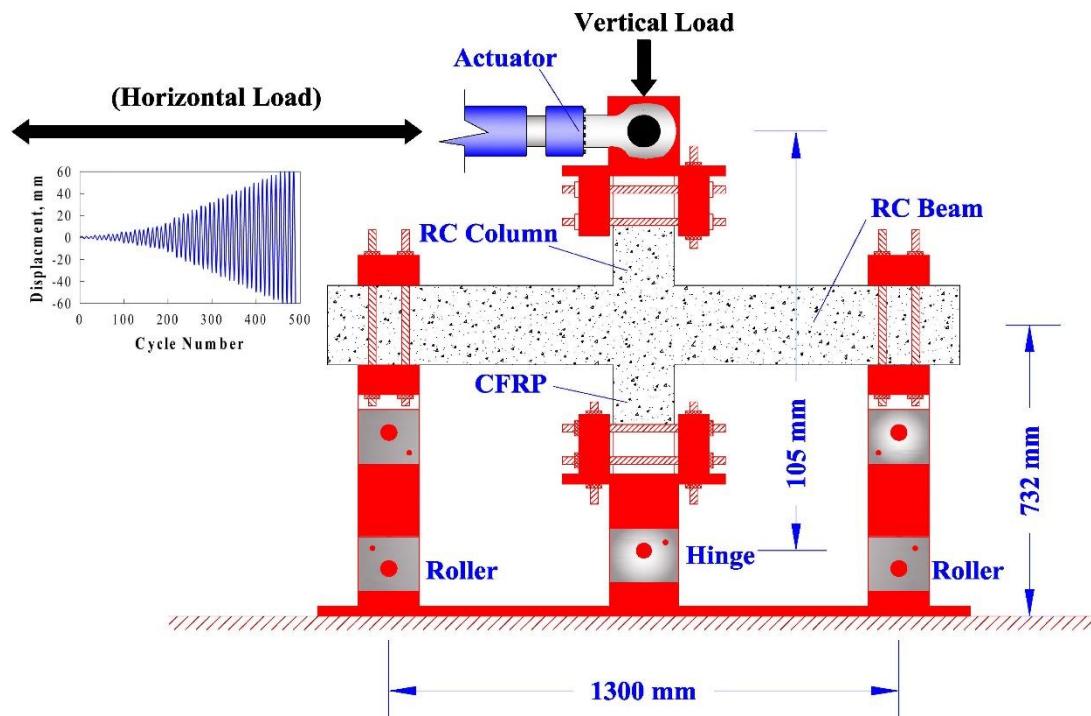
Figure: Specimen geometry, steel detailing, and setup

Next Steps: "Cyclic Behavior of Reinforced Concrete Beam-Column Joints Strengthening with FRP Composites"

Figure: Specimen geometry, steel detailing, and setup

Athens, 12 July 2022

Next Steps: "Cyclic Behavior of Reinforced Concrete Beam-Column Joints Strengthening with FRP Composites"
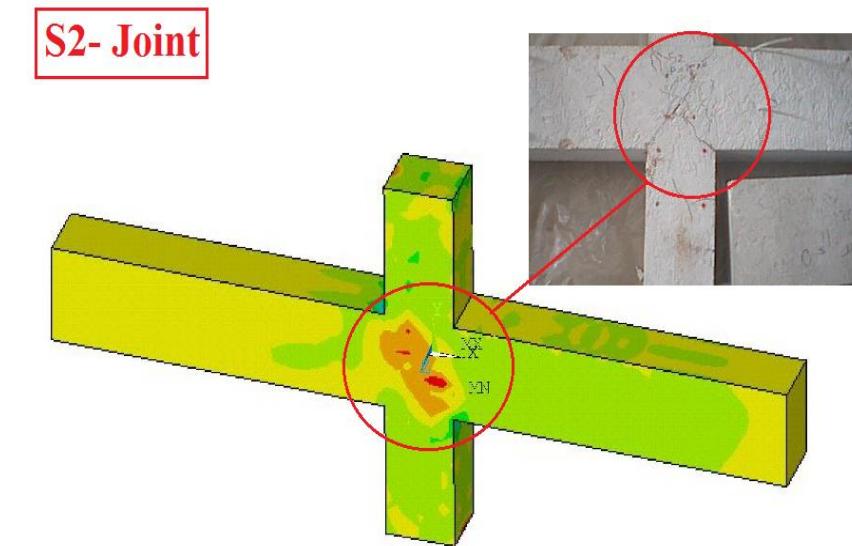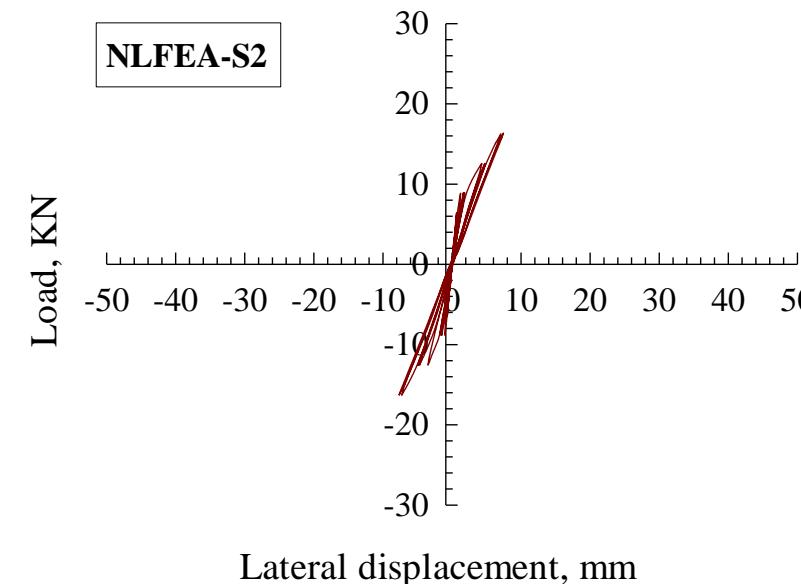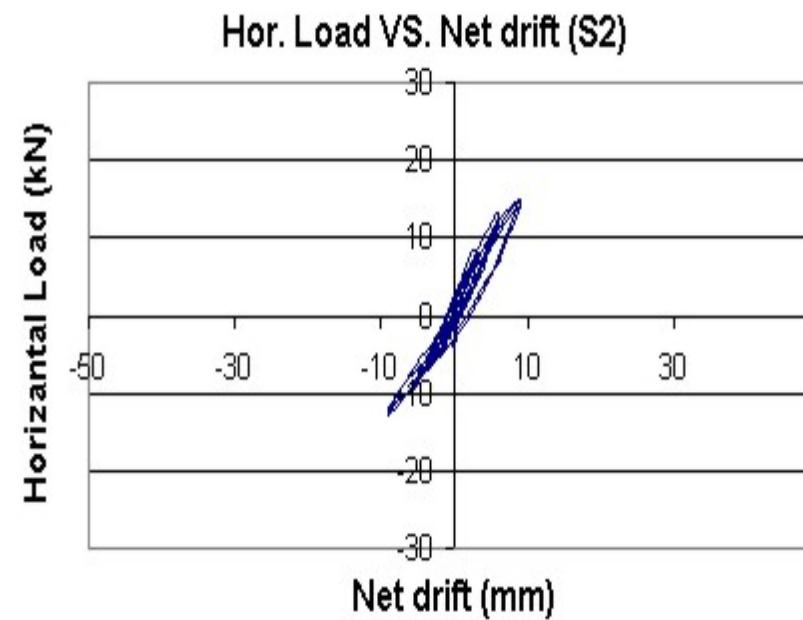
Figure: NLFEA and experimental horizontal load-net drift hysteresis loops for the validated joints

Athens, 12 July 2022

National Technical University of Athens
School of Civil Engineering

Secondment during ADDOPTML project
1.8.2021-12.21.2021 RISA Berlin, Germany
13.12.2021-31.7.2022 IDEA75 Bari, Italy

G.-Fivos Sargentis

ADDOPTML
Optimized 3D printed structures

June 2022

Contents

1. Description of the secondment
2. Subjects I've worked during the secondment
3. What was the outcome of my secondment (subject and deliverables)
4. Possibly next steps…

1.8.2021-12.21.2021 RISA Berlin, Germany

- From RISA, I collaborate with: Stephanos Camarinopoulos and Alexios Camarinopoulos working in the paper:

- Sargentis, G.-F.; Frangedaki, E.; Chiotinis, M.; Koutsoyiannis, D.; Camarinopoulos, S.; Camarinopoulos, A.; Lagaros, N.D. 3D Scanning/Printing: A Technological Stride in Sculpture. Technologies 2022, 10, 9. https://doi.org/10.3390/technologies10010009

(deliverable of WP8)

3D Scanning/Printing: A Technological Stride in Sculpture

G.-Fivos Sargentis [1,*], Evangelia Frangedaki [2], Michalis Chiotinis [1], Demetris Koutsoyiannis [1], Stephanos Camarinopoulos [3], Alexios Camarinopoulos [3] and Nikos D. Lagaros [4]

[1] Laboratory of Hydrology and Water Resources Development, School of Civil Engineering, National Technical University of Athens, Heroon Polytechneiou 9, 157 80 Zographou, Greece; mchiotinis@mail.ntua.gr (M.C.); dk@itia.ntua.gr (D.K.)

[2] Department III, Architectural Language, Communication and Design, School of Architecture, National Technical University of Athens, Heroon Polytechneiou 9, 157 80 Zographou, Greece; efraggedaki@arch.ntua.gr

[3] RISA Sicherheitsanalysen GmbH, Xantener Straße 11, 10707 Berlin, Germany; s.camarinopoulos@risa.de (S.C.); alexios.camarinopoulos@risa.de (A.C.)

[4] Institute of Structural Analysis and Antiseismic Research, School of Civil Engineering, National Technical University of Athens, Heroon Polytechneiou 9, 157 80 Zographou, Greece; nlagaros@central.ntua.gr

* Correspondence: fivos@itia.ntua.gr

Abstract: The creation of innovative tools, objects and artifacts that introduce abstract ideas in the real world is a necessary step for the evolution process and characterize the creative capacity of civilization. Sculpture is based on the available technology for its creation process and is strongly related to the level of technological sophistication of each era. This paper analyzes the evolution of basic sculpture techniques (carving, lost-wax casting and 3D scanning/printing), and their importance as a culture footprint. It also presents and evaluates the added creative capacities of each technological step and the different methods of 3D scanning/printing concerning sculpture. It is also an attempt to define the term "material poetics", which is connected to sculpture artifacts. We conclude that 3D scanning/printing is an important sign of civilization, although artifacts lose a part of material poetics with additive manufacturing. Subsequently, there are various causes of the destruction of sculptures, leaving a hole in the history of art. Finally, this paper showcases the importance of 3D scanning/printing in salvaging cultural heritage, as it has radically altered the way we "backup" objects.
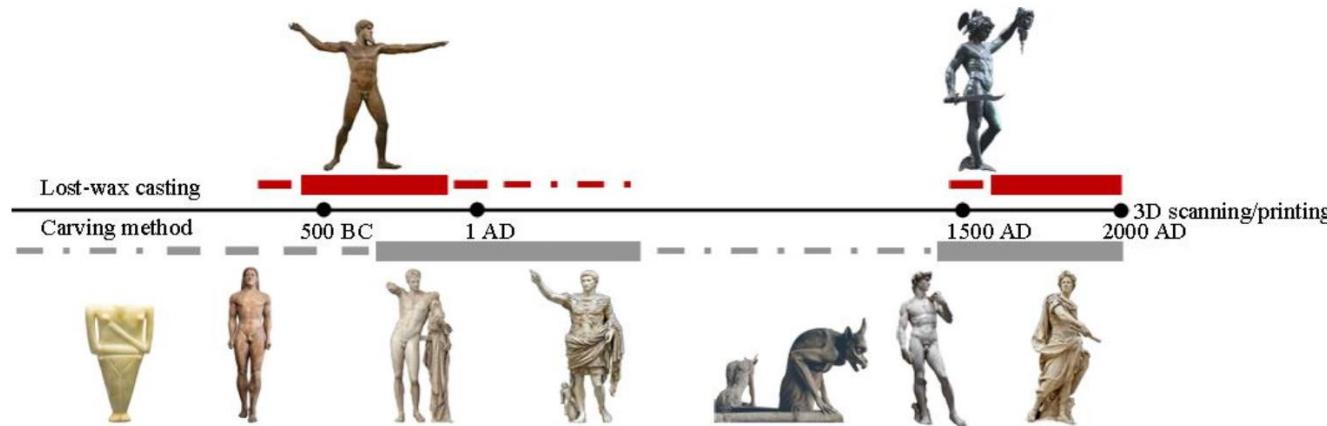
Keywords: 3D printing; 3D scanning; sculpture; art; technique; stride of civilization

- In this paper we show that three-dimensional printing offers new potential to sculpture creations, and its multiple applications enables new possibilities in art and technology. We characterize 3D printing as a Stride of Civilization

- pointing out the technical innovations of our partners in ADDOPTML
  - Ref 105: MX3D. Available online: https://mx3d.com/
  - Ref 107: Idonial. Available online: https://www.idonial.com/es/

1.8.2021-12.21.2021 RISA Berlin, Germany

- Our paper was in the top of the highly accessed articles of the journal for more than two months

1.8.2021-12.21.2021 RISA Berlin, Germany

In this period, another publication has been prepared, in the frame of my PhD thesis "Issues of prosperity…" under the supervision of my PhD supervisors Prof. D. Koutsoyiannis and Prof. N.D. Lagaros.

- Sargentis, G.-F.; Ioannidis, R.; Bairaktaris, I.; Frangedaki, E.; Dimitriadis, P.; Iliopoulou, T.; Koutsoyiannis, D.; Lagaros, N.D. Wildfires vs. Sustainable Forest Partitioning. Conservation 2022, 2, 195-218.
https://doi.org/10.3390/conservation2010013

(deliverable of WP6)

conservation   MDPI

Article

Wildfires vs. Sustainable Forest Partitioning

G.-Fivos Sargentis [1,*], Romanos Ioannidis [1], Ioannis Bairaktaris [1], Evangelia Frangedaki [2], Panayiotis Dimitriadis [1], Theano Iliopoulou [1], Demetris Koutsoyiannis [1] and Nikos D. Lagaros [3]

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[2] Department III, Architectural Language, Communication and Design, School of Architecture, National Technical University of Athens, 15780 Athens, Greece; efraggedaki@arch.ntua.gr
[3] Institute of Structural Analysis and Antiseismic Research, School of Civil Engineering, National Technical University of Athens, 15780 Athens, Greece; nlagaros@central.ntua.gr
* Correspondence: fivos@itia.ntua.gr

Abstract: There is a widespread perception that every year wildfires are intensifying on a global scale, something that is often used as an indicator of the adverse impacts of global warming. However, from the analysis of wildfires that have occurred in the US, Canada, and Mediterranean countries, a trend that justifies this perception could not be identified. Arguably, instead of blaming climate change, research on the mitigation of wildfires should be re-directed to forest management policy and practices. Forests are admirable and complex natural ecosystems, and fires, albeit devastating, can be attributed to both human activity and to natural processes that contribute to their rebirth, with the latter constituting an intrinsic and perpetual process of the forest ecosystem. Other than their important ecological value, forests are, in the 21st century, also a capital resource, for many people's livelihoods depend on them. In this study, we proposed a method for taking mitigation measures against wildfires based on the partitioning of forests, considering both the protection of the ecosystem and the inhabitants and aiming to utilize their co-dependent nature for the general protection and preservation of forests. As a case study, we analyzed the current devastating fire in Euboea (occurred in August 2021), initially in terms of the spatio-temporal progression of the actual wildfire that lasted several days and then by examining how an implementation of the proposed method in the study area could contribute to both the recovery of the ecosystem and the enhancement of the quality of life of the inhabitants as well as their long-term protection.

1.8.2021-12.21.2021 RISA Berlin, Germany

This publication

- Describes the phenomenon of wildfires and how this phenomenon affects the local communities who live in the forests

- Highlights the potentials of 3D printing in social recovery after disasters such as wildfires.

- It was selected as cover for journals' issue, and was in the top of the highly accessed articles of the journal for more than two months.

conservation

Wildfires vs. Sustainable Forest Partitioning

Volume 2 · Issue 1 | March 2022

MDPI
mdpi.com/journal/conservation
ISSN 2673-7159

13.1.2021-31.7.2022 IDEA75 Bari, Italy

In this period, a publication has been prepared, in the frame of my PhD thesis "Issues of prosperity…" under the supervision of Prof. N.D. Lagaros

- Sargentis, G.F.; Frangedaki, E.; Meletopoulos, I.; Kallioras, N.; Lagaros, N.D. Constructions with 3D printing. Innovative technological capabilities in the construction industry. Technical magazine KTIRIO, June 2022 (in Greek)
  https://zenodo.org/record/6785722#.YsCD7HZByUk

(deliverable of WP8)

which presented ADDOPTML project, pointing out the technical innovations of our partners in ADDOPTML.

13.1.2021-31.7.2022 IDEA75 Bari, Italy

This period I wrote and present in 14.6.2022 my PhD thesis "Issues of prosperity: Stochastic evaluation of data related to environment, infrastructures, economy and society". (deliverable of WP8) https://zenodo.org/record/6785733#.YsCEIHZByUk

13.1.2021-31.7.2022 IDEA75 Bari, Italy

- My PhD "Issues of prosperity: Stochastic evaluation of data related to environment, infrastructures, economy and society" was supported by the National Technical University of Athens and the European Union:

- OptArch project: "Optimization Driven Architectural Design of Structures" (No: 689983) belonging to the Marie Skłodowska-Curie Actions (MSCA) Research and Innovation Staff Exchange (RISE) H2020-MSCA-RISE-2015.

- ADDOPTML project: "ADDitively Manufactured OPTimized Structures by means of Machine Learning" (No: 101007595) belonging to the Marie Skłodowska-Curie Actions (MSCA) Research and Innovation Staff Exchange (RISE) H2020-MSCA-RISE-2020.

OPTARCH

ADDOPTML
Optimized 3D printed structures

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Thesis committee
Thesis supervisor D. Koutsoyiannis, Prof. N.T.U.A.
Advisory committee
1. D. Koutsoyiannis, Prof. N.T.U.A. (Supervisor)
2. N. Lagaros, Prof. N.T.U.A.
3. K. Hadjibiros. Prof. Emeritus N.T.U.A.
Evaluation committee
1. D. Koutsoyiannis, Prof. N.T.U.A. (Supervisor)
2. N. Lagaros, Prof. N.T.U.A.
3. K. Hadjibiros. Prof. Emeritus N.T.U.A.
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5. P. Thanopoulos Lecturer N.T.U.A.
6. N. Malamos Prof. University of Patras
7. S. Mavroudeas Prof. Panteion University

This research was supported by the National Technical University of Athens and the European Union:

OptArch project: "Optimization Driven Architectural Design of Structures" (No: 689983) belonging to the Marie Skłodowska-Curie Actions (MSCA) Research and Innovation Staff Exchange (RISE) H2020-MSCA-RISE-2015.

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13.1.2021-31.7.2022 IDEA75 Bari, Italy

- With the helpful contribution, of Dr. Giuseppe Leonardo Cascella his notable comments, the excellent environment and hospitality in IDEA75, in the frame of ADDOPTML I had the luxury to finalize my PhD thesis. (quotation from the Acknowledgments).

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I would like to thank the co-authors of the papers related to this thesis (alphabetically): Andreas Angelakis, Ioannis Bairaktaris, Michalis Chiotinis, John Christy, Panos Defteraios, Panayiotis Dimitriadis, Andreas Efstratiadis, Evangelia Frangedaki, Theano (Any) Iliopoulou, Romanos Ioannidis, Georgios Karakatsanis, Demetris Koutsoyiannis, Nikos Lagaros, Nikos Mamassis, Georgia-Konstantina Sakki, Paraskevi Siamparina, Stavroula Sigourou and Anastasios Tsonis. I would also like to thank the anonymous reviewers of the papers related to this thesis, and I own special thanks to Evangelia Frangedaki, Michalis Chiotinis and Theano (Any) Iliopoulou for English editing of this document.

I would like to thank Dr. Giuseppe Leonardo Cascella and Mr. Stefanos Camarinopoulos for their cooperation and the hospitality in their companies IDEA75 (Bari) and RISA (Berlin) during the research period in the frames of OPTARCH and ADDOPTML projects.

■ **General settings of the PhD thesis**

Living organisms pass through life seeking prosperity in a materialistic world.

There are different meanings of prosperity. Some people think that it is measured in money, others relate it to pleasure and life satisfaction, while others link it to spirituality. However, it could be argued that the basic human needs related to the Water, Energy and Food (WEF) compose a nexus not only necessary for the survival of humans, but able to explain their prosperity as well.

Unfortunately, decision-making in modern world is largely driven by economic aspects and monetarist policies. Koutsoyiannis (personal communication) notes that water, energy and food are not derived by money; rather money and economic growth derives from the availability and the access to water, energy and food.

In this thesis, we study critical issues of prosperity rationally, using publicly available data, historical evidences and stochastic tools. The studied issues are based on the WEF nexus but extend to various other societal, environmental and cultural aspects of human life in societies, ranging from social stratification and urban clustering, to the aesthetic quality of surrounding environment.

Next steps

- This period I am Guest Editor in a Special Issue about Water-Energy-Food Nexus for Sustainable Land Management at Land.

- With my collogues in IDEA75 we are discussing a paper about the conflicts of the crisis in Ukraine in Water-Food-Energy Nexus.

- Cities are isolated clusters which are highly consumers as 75% of global primary energy and 80% of global food is consumed in urban areas while urban population is only 56% . In addition, EU countries are also focus in secondary or tertiary economic sectors which are not connected with Water-Energy-Food nexus. Therefore are venerable to threats as energy poverty or food crises.

land

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IMPACT FACTOR 3.905

CITESCORE 3.2

Water - Energy - Food Nexus for Sustainable Land Management

Guest Editors
Dr. G.-Fivos Sargentis, Dr. Theano Iliopoulou, Dr. Andreas Angelakis, Dr. Nikolaos Malamos

Deadline
20 December 2022

Special Issue

mdpi.com/si/118383

Invitation to submit

- In this paper, I would like to show the dynamics of 3D printing to transform the cities to smaller clusters which could be self-sufficient, as they could be connected to Water-Energy-Food nexus.

- This could be an effective defense to energy poverty and food crises.

Next steps

Sculpture

- Until now, my artworks were with traditional methods: bronze (lost-wax casting) or marble.

https://zenodo.org/record/4740354#.YsB9P3ZByUI
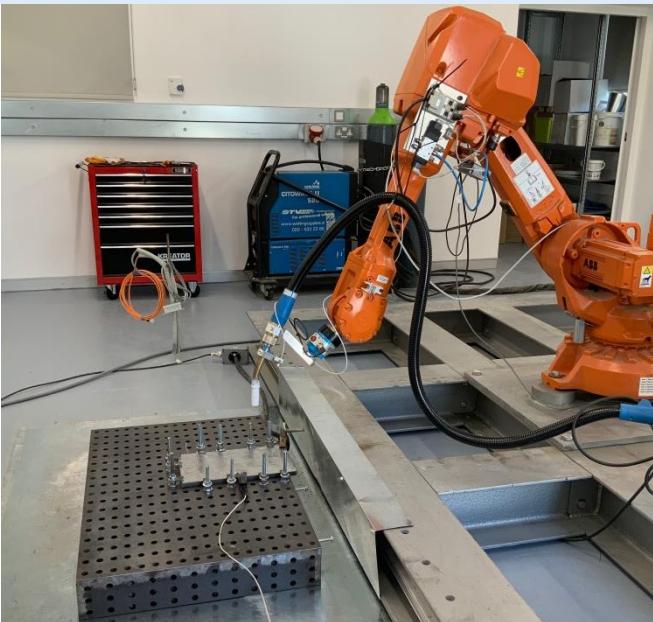
- After my secondment and my research, I will continue the cooperation with ADDOPTML project and the partners of ADDOPTML, in order to apply the findings of the research in my artwork.

ADDitively Manufactured OPTimized Structures by means of Machine Learning

Secondment of Dr. Stavros Chatzieleftheriou

from *Structures & Sensors* to *University of Cyprus*

During my secondment in UCY I had a chance to collaborate with Prof. Phocas, Dr. Kontovourkis and Dr. Hadjipantelis and visit the WAAM (Wire Arc Additive Manufacturing) laboratory that is set up there.
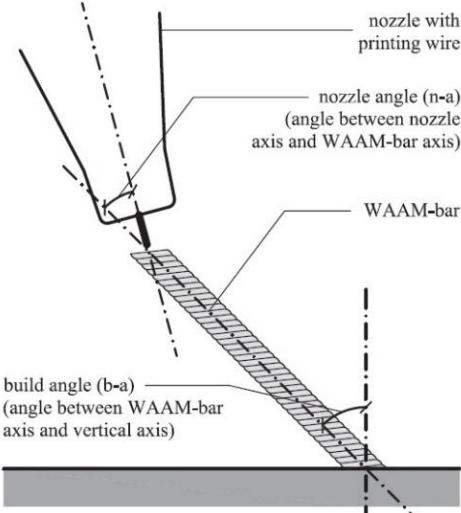
I had a chance to get acquainted with 3D printing methods for steel like WAAM while UCY staff is friendly and willing to assist us in all relevant matters. They also have a variety of 3D printed specimens from other material like plastic and powder-binder.
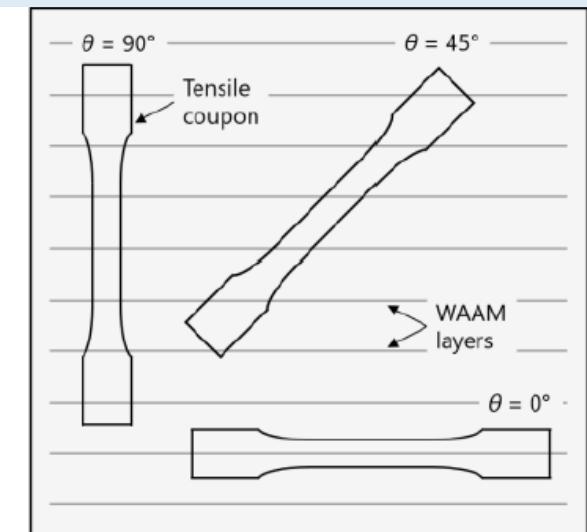
Along with NTUA researchers we collaborated on WP's 1,2 and 3.
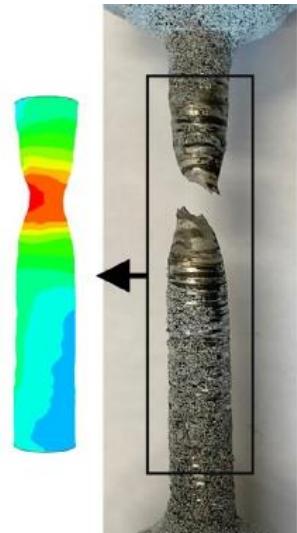
In WP1 some non linear FEM models (incorp. Linear buckling and GMNI Analyses) have been incorporated in the machine learning assisted topology optimization process design, in WP 2 constitutive relations through testing and machine learning for 3D printed specimens will be developed while in WP 3 experimental verification of the developed framework will be sought
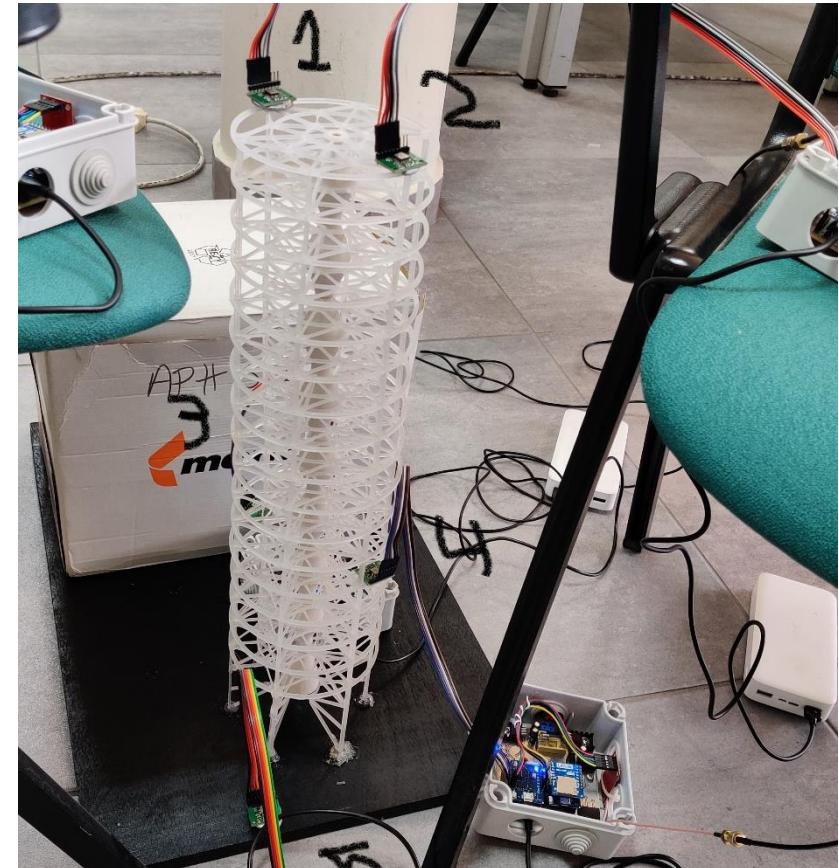

There are a series of parameters that affect the structural performance of the specimens like the printing angle and material anisotropy stemming from coupon orientation
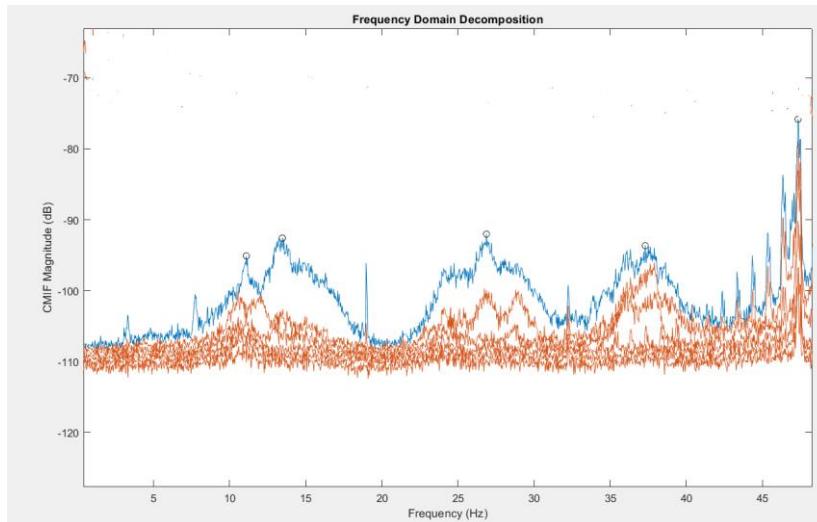
Machine learning aided topology optimization design process can benefit from well calibrated FEM based on experimental tests like tensile testing but also from modal analysis tests in order to calibrate also based on dynamic characteristics of the specimens.
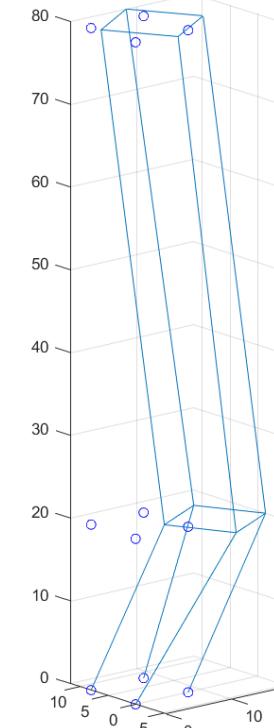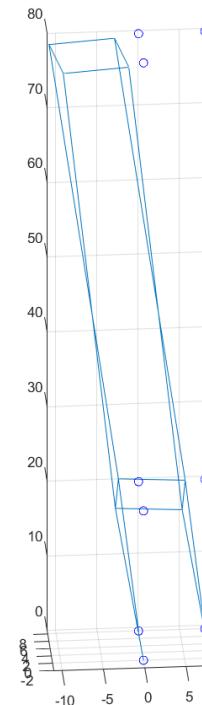
In this context we also conducted some initial modal analysis tests in plastic 3D printed specimens, awaiting for the final steel and concrete specimens

University of Cyprus
Department of Architecture

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MODAL ANALYSIS OF 3D PRINTED STRUCTURE RESULTS
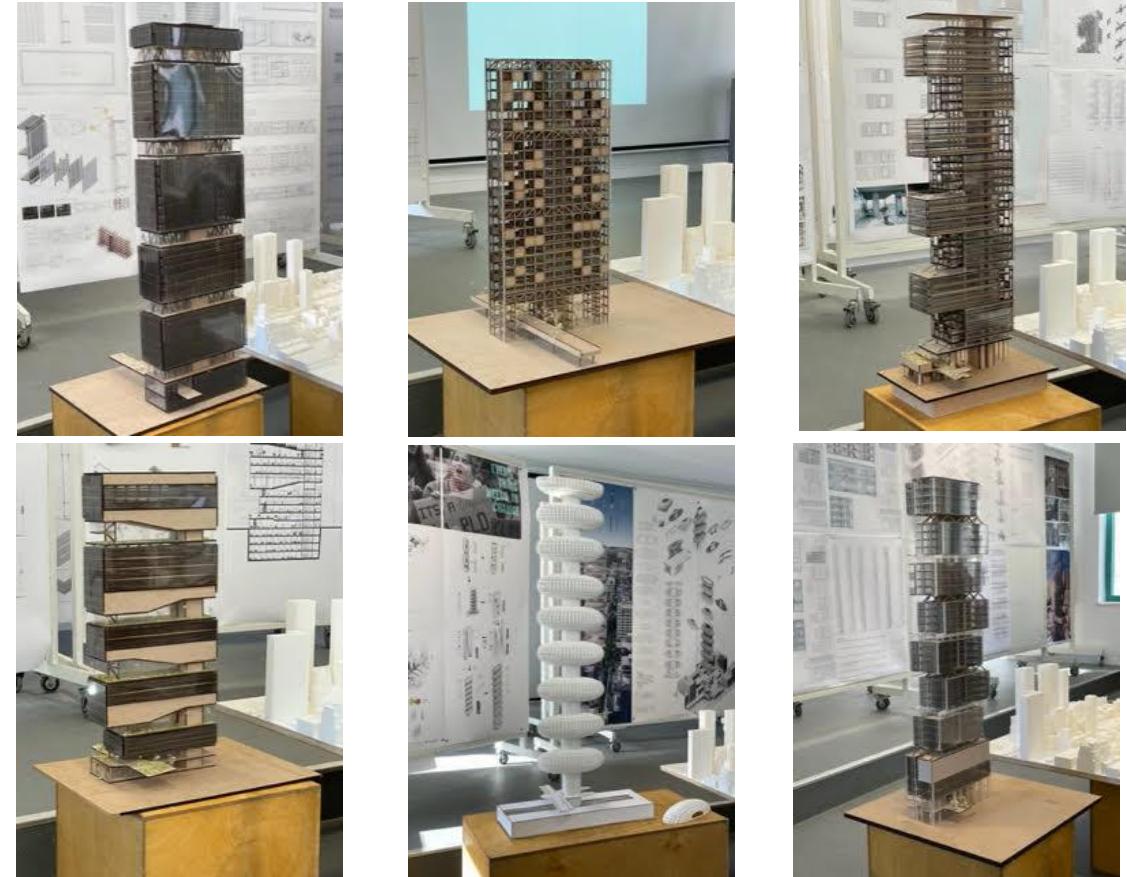
Flattened bell curves suggest high damping rations attributed to damaged components

Translational Mode at 11.1 Hz

Bending Mode at 47.3 Hz

Fuhrer collaboration with UCY in the preliminary design of a slender tall skyscraper in the context of Architectural Synthesis and Technology course regarding structural form, stiffness, mass and damping distribution to achieve satisfactory performance.

This will be achieved by validating and updating structural models based on <u>measured dynamic characteristics</u> of 8 mock up variations of the tall building
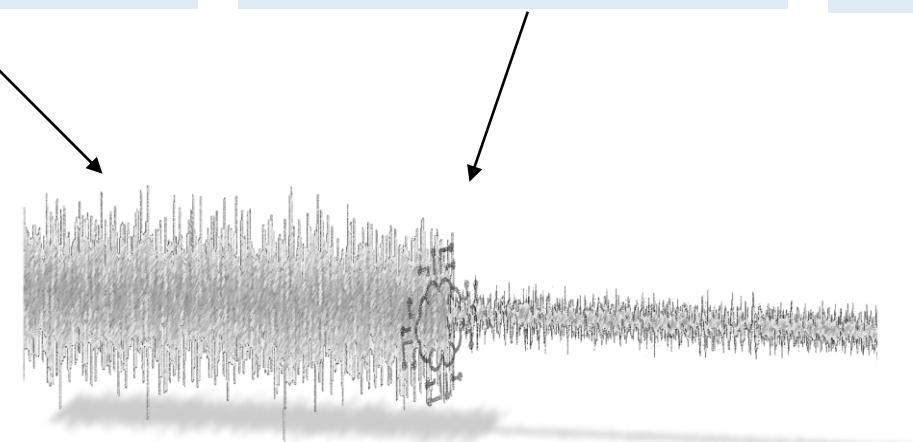
In the context of ADDOPTML we had a chance to also collaborate with seconded Spyros Damikoukas from NTUA to RISA Sicherheitsanalysen GmbH Berlin in order to incorporate his work on the Machine Learning aided denoising of signals in the measurements performed with S&S sensors in structures.
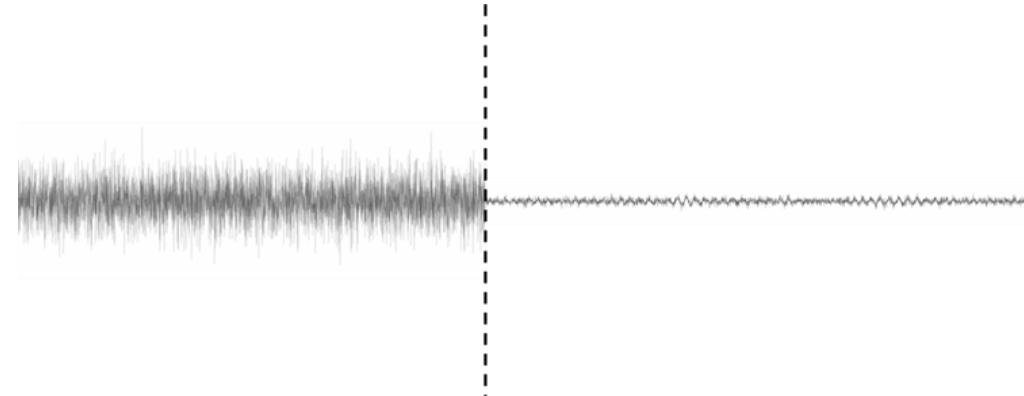
Data of ambient response of a structure as is from deployed sensors
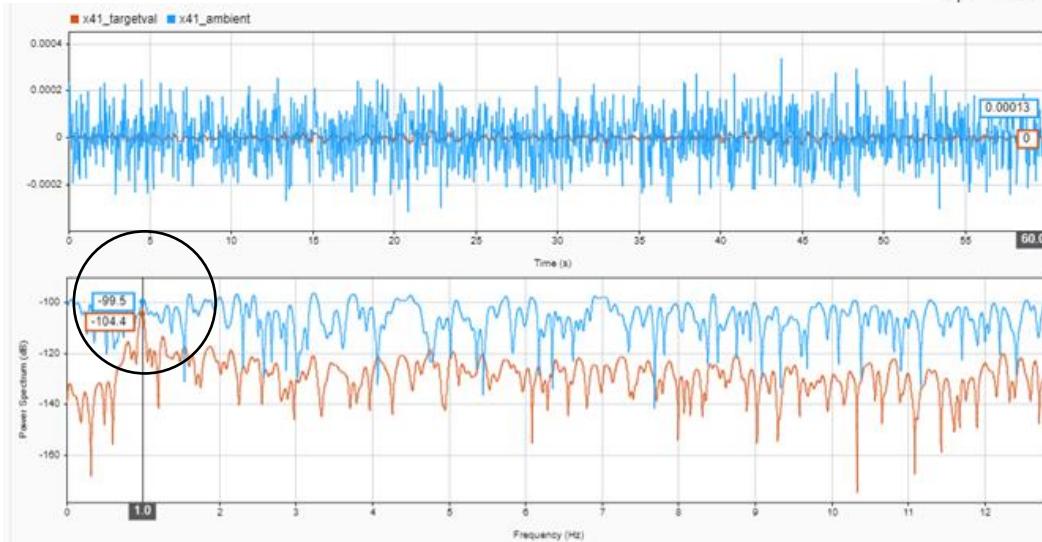
Denoising Autoencoder (Neural Network)

Denoised acceleration timehistory of ambient response of a structure
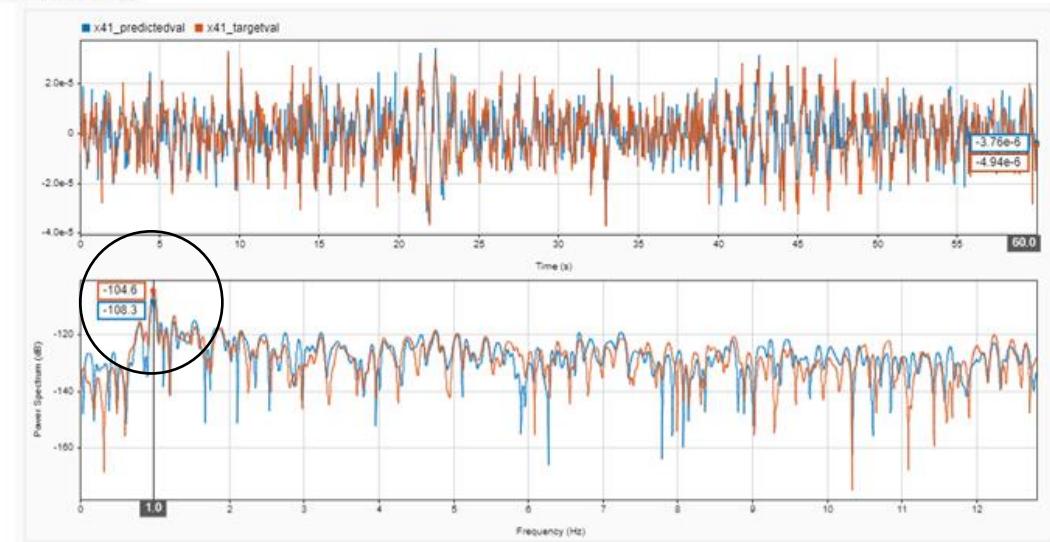
The aim of his work is to take advantage of the power of neural networks and their image detection capabilities, in cases of high noise environments. A denoising autoencoder is used, which learns to denoise noisy ambient acceleration signals and return as a result the clean one.

Comparison of frequency content between **target (clean) signal** (orange) and signal with **electronic noise** (blue) – Frequency 1.0Hz.

➢ **Frequency in noisy signal is under question and not easily distinguished**

Comparison of frequency content between **target (clean) signal** (orange) and **prediction** (blue) – Frequency 1.0Hz.

➢ **Frequency in denoised signal is dominant, easily distinguished without error compared to the true value signal**

This work is submitted & under review:

- Damikoukas, S., Lagaros, N.D., *Machine learning based denoising of ambient vibration generated structural response signals* Bull Earthquake Eng, 2022

University of Cyprus
Department of Architecture

Unquake
Smart safer cities

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ADDitively Manufactured OPTimized Structures by means of Machine Learning

Midtem meeting - Athens 12/07/2022
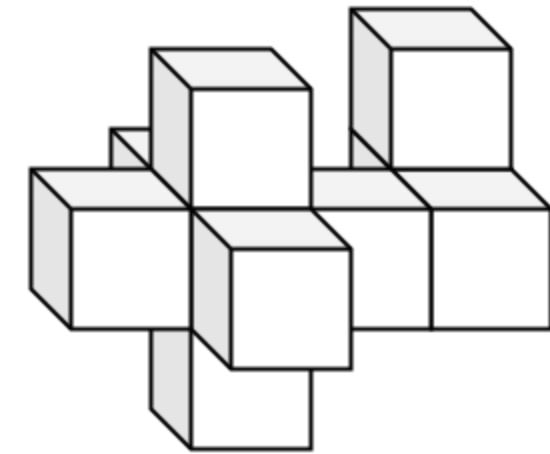
idee75	**Vincenzo Zeffiri**
	Christodoulos Fragkoudakis and **Markos Karampatsis** Secondment @IDEA75 during 01/06/2021 - 30/11/2021

Our background

- Christodoulos Fragkoudakis holds a Ph.D. in computer science from the Electrical and Computer Engineering Department at NTUA.

- Markos Karampatsis has a master's degree in information systems from Brunel Univerisity.

- We both are special teaching personnel of the ECE school at NTUA.

- During the last ten years, we have been in close collaboration with the research team of professor Nikos Lagaros, participating in programming classes, collaborating on research projects, and developing an interest in the cloud computing transition of everyday civil engineering tasks.

- We have applied to move as special teaching personnel at the Civil Engineering School at NTUA.

IDEA75 hosting

- Vincenzo Zeffiri was an excellent host and helped us immensely with our vision toward a cloud computing transition of standard civil practices.

- We decided to develop a library in Python for calculating the outer shell, aka STL representation, of unit cube complexes.

- Machine Learning optimizations generate dense unit cube complex representations. These representations need to convert to STL for 3D printing.

- A successful implementation in Python will lead to easy porting to Javascript for immediate use in web applications while serving as a backend for cloud computing solutions.

A 3D unit cube complex

Our `ucc2stl` **Python Library**

```python
from ucc2stl import CuboidComplex
```
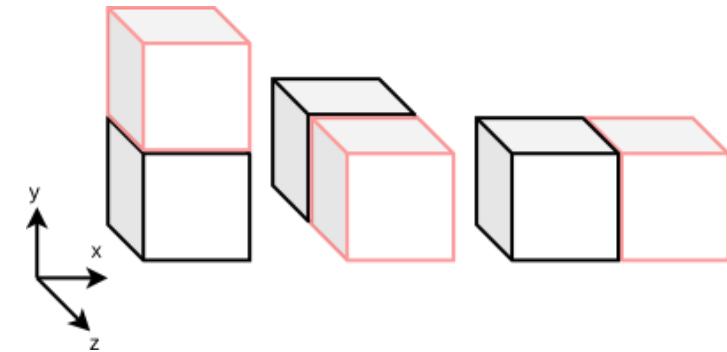
- We developed a 3D Points and Vectors Python kernel.

- Our kernel supports standard geometric operations like point subtractions and translations, vector products, etc.

- We developed a Python class for the cube's face representation.

- Our Cuboid class utilizes the Face class for an enhanced cube data structure.

- Our CuboidComplex class comprises Cuboid instances and gradually keeps a consistent outer shell representation as built.

Cuboid ordering and outer shell calculations

- Unit cubes in 3D have a well-defined ordering concerning their centroids:

$$c = (x, y, z) = \left(\frac{\sum_{i=1}^{8} x_i}{8}, \frac{\sum_{i=1}^{8} y_i}{8}, \frac{\sum_{i=1}^{8} z_i}{8} \right)$$

- A "bigger" (colored in the image) cube is around a bigger centroid.

- We built our CuboidComplex instances gradually, discarding the cube face between the "smaller" and the "bigger" cube.

Test cases of Unit Cube Complexes

- We tested our CoboidComplex class under various corner cases and an actual result of a Machine Learning optimization outcome.

- We depict the python implementation and the resulting STL output in what follows.

- We used Paraview to visualize the STL output and exported the scene to a PDF file.

- We used the `pdftoppm` Linux utility to generate the PNG images.
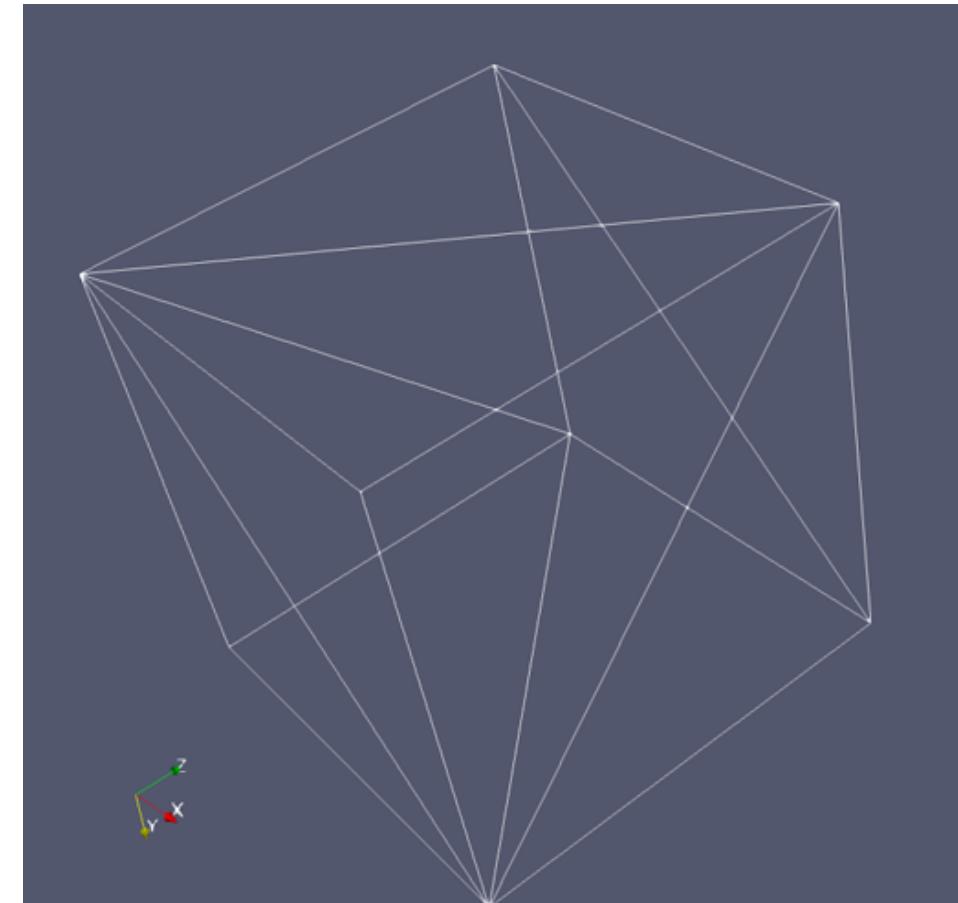
A `CuboidComplex` of one cube

```python
from ucc2stl.cuboids import Cuboid, CuboidComplex
from ucc2stl import Point, Vector

x0 = Point(0, 0, 0)
x1 = Point(1, 0, 0)
x2 = Point(1, 1, 0)
x3 = Point(0, 1, 0)
x4 = Point(0, 0, 1)
x5 = Point(1, 0, 1)
x6 = Point(1, 1, 1)
x7 = Point(0, 1, 1)

cuboid = Cuboid([x0, x1, x2, x3, x4, x5, x6, x7])
complex = CuboidComplex([cuboid.vertices])
complex.shell()
complex.export_stl()

# Prints the following:
# Started inserting cuboids ... Done inserting 1 cuboids
# Started outer shell calculation  ... Done
# There are 8 vertices and 12 triangles.
```
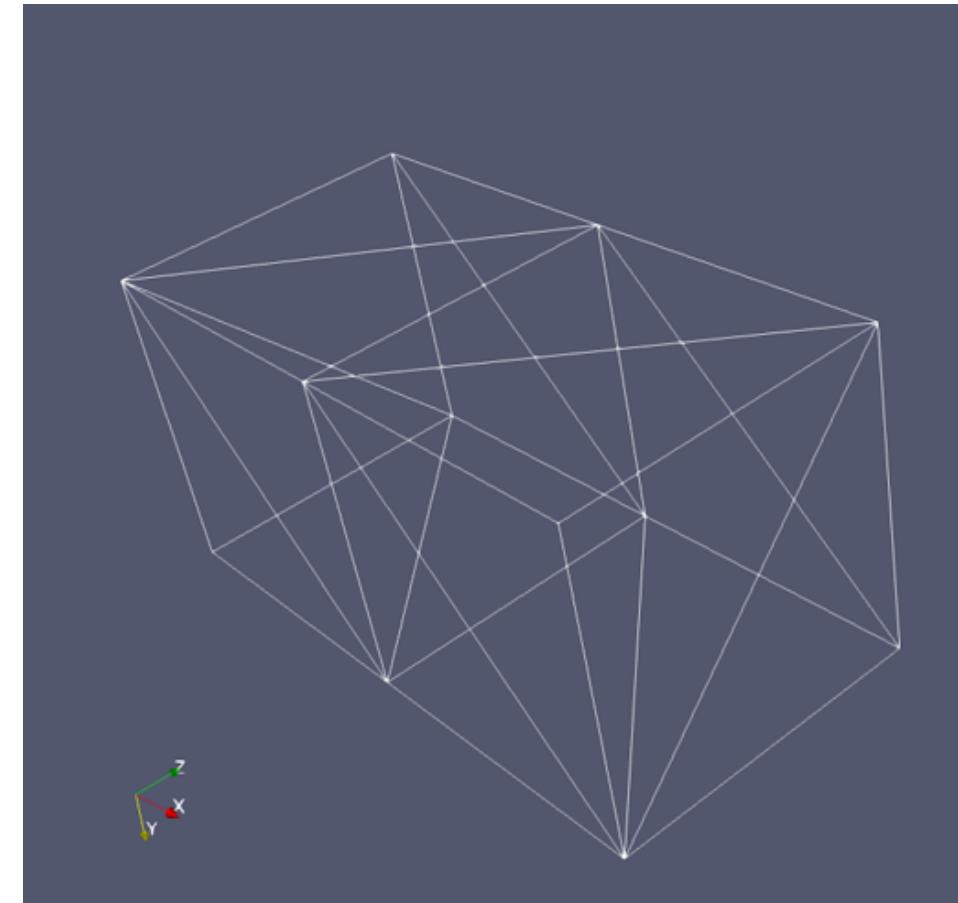
# A `CuboidComplex` of two cubes

```python
from ucc2stl.cuboids import Cuboid, CuboidComplex
from ucc2stl import Point, Vector

x0 = Point(0, 0, 0)
x1 = Point(1, 0, 0)
x2 = Point(1, 1, 0)
x3 = Point(0, 1, 0)
x4 = Point(0, 0, 1)
x5 = Point(1, 0, 1)
x6 = Point(1, 1, 1)
x7 = Point(0, 1, 1)

cuboid_list = []
cuboid0 = Cuboid([x0, x1, x2, x3, x4, x5, x6, x7])
vector = Vector(1,0,0)
cuboid1 = cuboid0.translate(vector)
complex = CuboidComplex([cuboid0.vertices, cuboid1.vertices])
complex.shell()
complex.export_stl()

# Prints the following:
# Started inserting cuboids ... Done inserting 2 cuboids
# Started outer shell calculation  ... Done
# There are 12 vertices and 20 triangles.
```

A `CuboidComplex` of four cubes
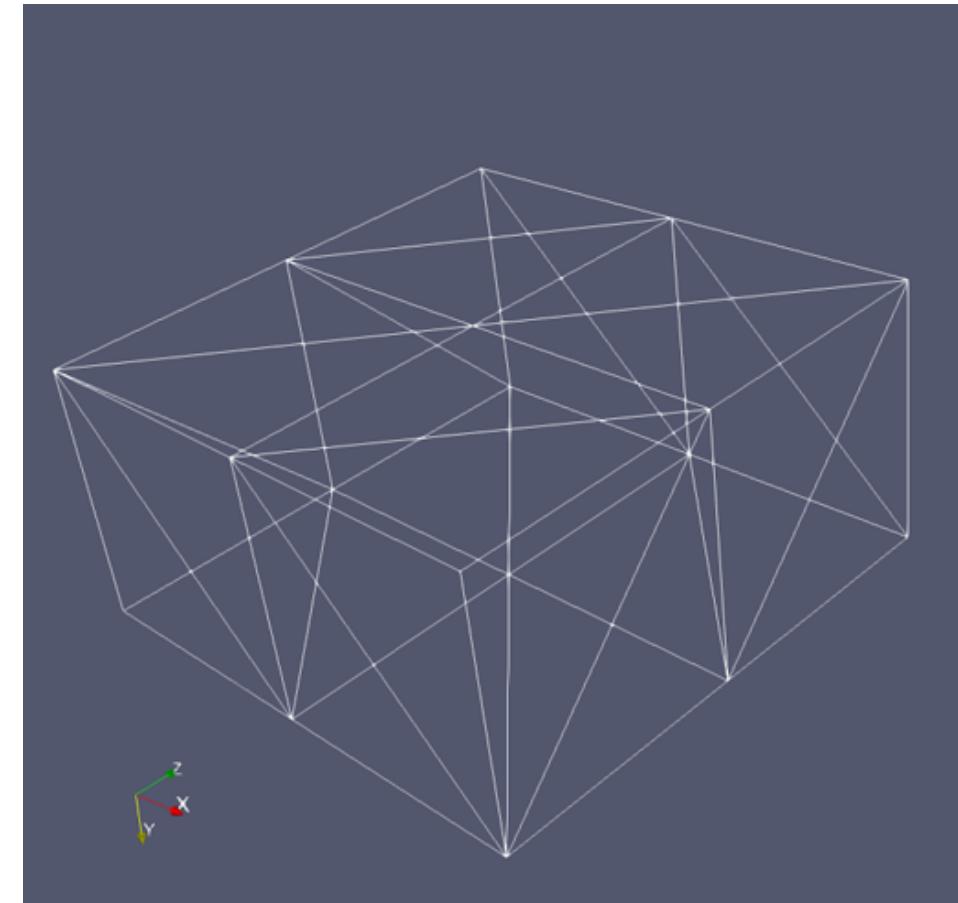
```python
from ucc2stl.cuboids import Cuboid, CuboidComplex
from ucc2stl import Point, Vector

x0 = Point(0, 0, 0)
x1 = Point(1, 0, 0)
x2 = Point(1, 1, 0)
x3 = Point(0, 1, 0)
x4 = Point(0, 0, 1)
x5 = Point(1, 0, 1)
x6 = Point(1, 1, 1)
x7 = Point(0, 1, 1)

cuboid = Cuboid([x0, x1, x2, x3, x4, x5, x6, x7])
cuboid_list = [cuboid]
translation_vectors = [Vector(1, 0, 0), Vector(0, 0, 1), Vector(1, 0, 1)]

for vector in translation_vectors:
    cuboid_list.append(cuboid.translate(vector))

complex = CuboidComplex([cuboid.vertices for cuboid in cuboid_list])
complex.shell()
complex.export_stl()

# Prints the following
# Started inserting cuboids ... Done inserting 4 cuboids
# Started outer shell calculation  ... Done
# There are 18 vertices and 32 triangles.
```
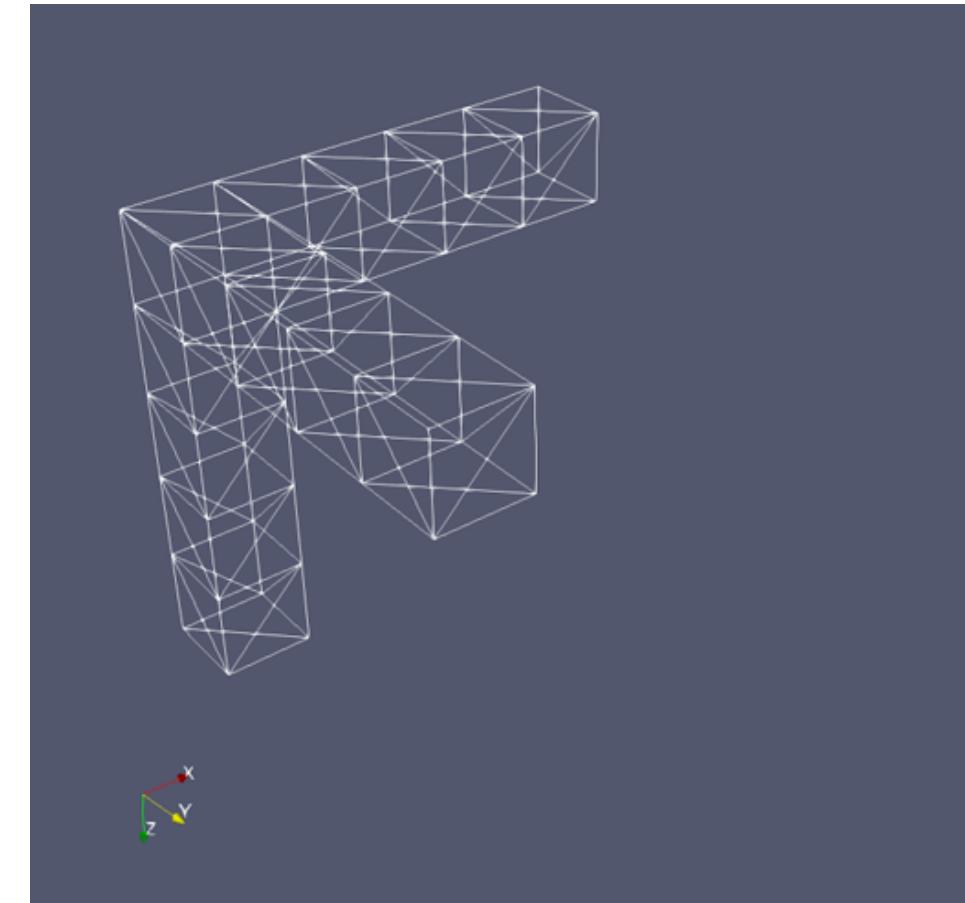
A `CuboidComplex` of three beams

```python
from ucc2stl.cuboids import Cuboid, CuboidComplex
from ucc2stl import Point, Vector

x0 = Point(0, 0, 0)
x1 = Point(1, 0, 0)
x2 = Point(1, 1, 0)
x3 = Point(0, 1, 0)
x4 = Point(0, 0, 1)
x5 = Point(1, 0, 1)
x6 = Point(1, 1, 1)
x7 = Point(0, 1, 1)
x = y = z = Cuboid([x0, x1, x2, x3, x4, x5, x6, x7])
cuboid_list = [x]

for i in range(4):
    x = x.translate(Vector(1, 0, 0))
    y = y.translate(Vector(0, 1, 0))
    z = z.translate(Vector(0, 0, 1))
    cuboid_list += [x, y, z]

complex = CuboidComplex([cuboid.vertices for cuboid in cuboid_list])
complex.shell()
complex.export_stl()
# Prints the following
# Started inserting cuboids ... Done inserting 13 cuboids
# Started outer shell calculation  ... Done
# There are 56 vertices and 108 triangles.
```

Nodes - Connectivity - Density
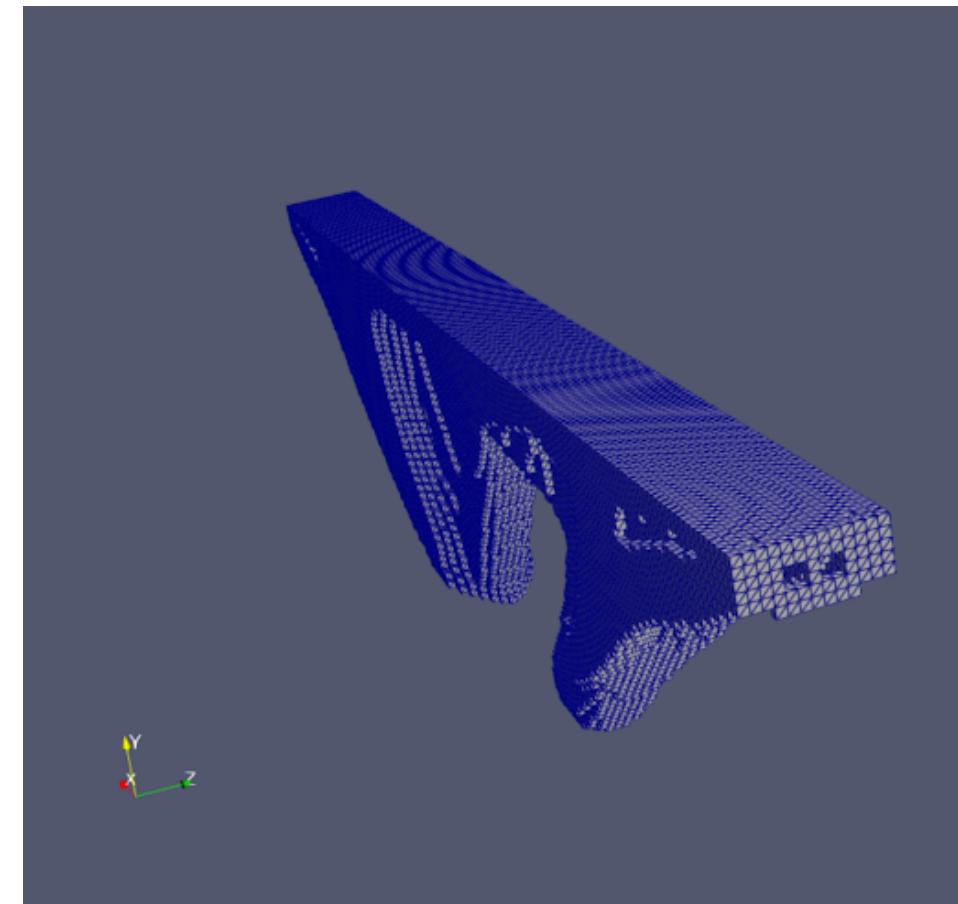
- A usual representation of finite element methods analysis results is the nodes-connectivity representation.

- As a result of an optimization process, there is an extra density parameter for every connectivity construct.

- We developed helper functions to convert this information to use Python lists representations.

- We had a set of nodes-connectivity-density files regarding the optimization output of a finite element analysis process.

- We utilized our helper functions to convert this set of files to a suitable input of our CuboidComplex class.

An example from a real optimization analysis

```python
from ucc2stl import dense_cuboids, CuboidComplex

cuboids = dense_cuboids("Node.txt", "Connectivity.txt", "density.txt", 0.3)
complex = CuboidComplex(cuboids)
complex.shell()
complex.export_stl()

# Prints the following:
# Opening Node.txt ... Read 129444 values
# Opening Connectivity.txt ... Read 117000 values
# Opening density.txt ... Read 117000 values
# Filtering dense cuboids ...Filtered 37148 dense cuboids
# Started inserting cuboids ... Done inserting 37148 cuboids
# Started outer shell calculation  ... Done
# There are 25264 vertices and 50572 triangles.
```

Future work

- Develop a frontend application that submits nodes-connectivity-density data to our `ucc2stl` backend.

- Port our Python implementation into Javascript for a pure browser experience.

- Our STL output is already successfully recognized by the `viewstl` javascript library.