



DIPARTIMENTO DI STRUTTURE PER L'INGEGNERIA E L'ARCHITETTURA
CORSO DI DOTTORATO DI RICERCA IN
INGEGNERIA STRUTTURALE GEOTECNICA E RISCHIO SISMICO

XXXIX CICLO

Il sottoscritto prof. Costantino Menna

(PO PA X RU RTD) afferente al Dipartimento di Strutture per
l'Ingegneria e l'Architettura - S.S.D. ICAR/09 Tecnica delle Costruzioni

CHIEDE

di essere inserito nell'elenco dei tutor per il XXXIX ciclo.

1. Curriculum del proponente (max 500 parole)

Costantino Menna is currently Associate Professor of Structural Engineering at the Department of Structures for Engineering and Architecture of the University of Naples Federico II. He graduated in Materials Engineering in 2009 and received his Ph.D. in Materials Engineering and Structures in 2013 at the same university, working on damage modeling of advanced composite materials. In April 2018 he obtained the National Scientific Qualification as Associate Professor (ICAR-09).

He is involved in several multidisciplinary research activities mainly focused on advanced materials and technologies for civil and industrial applications, including: experimental assessment and theoretical modeling of innovative materials used for structural retrofit of existing structures, finite element modeling, sustainability assessment procedures, and additive manufacturing in the construction industry. He was visiting research scholar in several foreign institutions: École Polytechnique de Montréal (Canada), Department of Engineering Science and Mechanics of Penn State University (USA), Laboratoire de Mécanique des Solides of Ecole Polytechnique (Paris), University of Greenwich (UK).

He is chair of Task Group 2.11: “*Structures made by digital fabrication*” of fib and member of RILEM Technical Committee 276-DFC. In 2019 was selected as “User-Committee” member for the grant funded by the Dutch National Science Foundation entitled: “Systematic development of printable SHCCs” (2019-2021). He is external expert for the European Commission for the Horizon 2020 entitled: “Integrated techniques for the seismic strengthening and energy efficiency of existing buildings”.

He is currently PI of the national funded projects entitled:

- TOMORROW: TOpology & Material Optimization using additive manufactuRing to maximize stRuctural and thermal perfOrmances of building



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Walls

- Digi-Beton: digital fabrication of construction systems made of AAC.
- INTERACTS: INtegrATED and Reliable ApproaChes for susTainability assessment of existing buildingS, funded by PROGRAMMA STAR Linea 1.

He is holder of 5 national and 1 international patents, co-founder of the Spinoff FED, Future Environmental Design, and of the Spinoff ETESIAS s.r.l.

He is author of more than 50 scientific papers published in international peer-reviewed journals or presented at international conferences, and 6 book chapters.

2. Dottorandi dei quali il proponente è stato tutor nell'ultimo triennio

<i>n. 1</i>	<p><i>Ph.D. scholarship funded within the industrial programme (company: Ekoru s.r.l.)</i></p> <p><i>Ph.D. candidate: Marco Giulivo - Structural, Geotechnical Engineering and Seismic Risk - XXXVIII cycle</i></p>
<i>n. 2</i>	<p><i>Ph.D. scholarship funded within the programme: PON FSE-FESR Ricerca e Innovazione 2014-2020. Azione I.1 – Dottorati innovativi a caratterizzazione industriale</i></p> <p><i>Ph.D. candidate: Laura Esposito - Structural, Geotechnical Engineering and Seismic Risk - XXXIV cycle</i></p>

3. Titolo della ricerca proposta

Design, 3D Printing and Experimental Assessment of Reinforced Concrete Structures for Renewable Energy Applications

4. Area Tematica

Ingegneria Geotecnica



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Ingegneria Strutturale

Rischio Sismico

5. Tipologia di borsa per la quale si propone il progetto

Ateneo

DM 117 (Investimento 3.3)
ENEL GREEN POWER

DM 118 (Investimento 4.1 P.A.)

DM 118 (Investimento 4.1 generici)

DM 118 (Investimento 4.1 Patrimonio culturale)

6. Sintesi del progetto di ricerca (max 500 parole. Stato dell'arte, obiettivi e breve programma previsto per le attività)

State of the Art

Digital Fabrication technologies utilizing Concrete (DFC) have recently enabled form freedom for the manufacturing of a variety of concrete-made objects having mainly architectural and aesthetic functions. Structural elements or civil/building structures made by DFC are demonstrating a high engineering potential, mainly for the opportunity of tailoring the final shape while optimizing the structural/functional performance, material use, sustainability targets, overall costs and architectural effectiveness. The variety of available DFC methods can be generally grouped based on the process adopted: (i) extrusion process, (ii) formwork printing, (iii) temporary supports, slipforming, (v) particle bed fusion or even (vi) hybrid techniques. However, DFC projects aimed to deploy structurally efficient DFC constructions or components have to often tackle the lack of a clear common approach to the structural engineering as well as the adaptation of current design knowledge to the specific DFC production particularities.



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Objectives

The primary objective of the proposed PhD project is to address the fundamental structural issues associated to DFC structures towards achieving the full potential offered by this revolutionary way of producing concrete products. Particular emphasis will be given to structures employed in the Renewable Energy sector, such as electrical substations, innovative foundations and support structures for offshore applications. These are mostly related to the particularities of DFC products (e.g., cold joint, imperfection, orthotropy etc.) that represent a significant issue for code-compliant applications. The final objective of the PhD project will be the proposal of “re-thinking” and/or adapting current knowledge on conventional reinforced concrete structures to the specific production route offered by the different digital fabrication technologies, potentially leading to new testing/simulations and/or overall design strategies required to spread the use of these technologies.

Program

The PhD research activities will be focused on the structural issues associated to the specific mechanical aspects characterizing the structures produced by DFC. In particular, the following program is proposed:

- **1st year:** Experimental and numerical investigation on hardened concrete material performances to quantify design parameters (e.g., anisotropy, cold joint, weak directions etc.); corresponding mechanical effects (e.g., compression capacity, mode of failure etc.) on sub-components (e.g., concrete panels, small scale concrete beams/columns);
- **2nd year:** Experimental and numerical investigation on size/scale effects of end-products in the hardened state (i.e., building component, full scale house etc.); shape-related mechanical effects (e.g., deriving from a specific DFC technique).
- **3rd year:** Steel reinforcement placement: quantities, overall achievable ductility, interaction with concrete; modelling of the overall structural behavior (e.g., analytical formulations, numerical etc.) to obtain code-compliant capacity models. Demonstration activities: apply the entire design-to-fabrication route to a real case study.

The fundamental knowledge produced according to the program will support the introduction of new design criteria in the field of DFC, that will be able to guarantee



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structural integrity, serviceability, ductility and code-compliance.

7. Eventuali pubblicazioni del tutor sul tema di ricerca (max 10)

1. Gebhard, L., Esposito, L., Menna, C., & Mata-Falcón, J. (2022). Inter-laboratory study on the influence of 3D concrete printing set-ups on the bond behaviour of various reinforcements. *Cement and Concrete Composites*, 133, 104660.
2. Bos, F. P., Menna, C., Pradena, M., Kreiger, E., da Silva, W. L., Rehman, A. U., ... & Mechtcherine, V. (2022). The realities of additively manufactured concrete structures in practice. *Cement and Concrete Research*, 156, 106746.
3. Menna, C., Mata-Falcón, J., Bos, F., Vantighem, G., Ferrara, L., Asprone, D., Salet, T., & Kaufmann, W. (2020). *Opportunities and challenges for structural engineering of digitally fabricated concrete*. Under review in *Cement & Concrete Research*.
4. Casagrande, L., Esposito, L., Menna, C., Asprone, D., & Auricchio, F. (2020). *Effect of testing procedures on buildability properties of 3D-printable concrete*. Accepted for publication in: *Construction and Building Materials*.
5. Asprone, D., Menna, C., et al. (2020). *Structural design and testing of digitally fabricated concrete structures*. Chapter 6 of RILEM book series on the work done by Technical Committee 276-DFC. Springer Edition.
6. Esposito, L., Fioretti, M., Cucchi, M., Lo Monte, F., Menna, C., Moro, S., ... & Ferrara, L. (2019). *Early age fracture performance of 3D printable fiber reinforced cementitious composites*. In 5th International Workshop on the New Boundaries of Structural Concrete (pp. 445-454).
7. Pastore, T., Mercuri, V., Menna, C., Asprone, D., Festa, P., & Auricchio, F. (2019). *Topology optimization of stress-constrained structural elements using risk-factor approach*. *Computers & Structures*, 224, 106104.
8. Asprone, D., Menna, C., Bos, F. P., Salet, T. A., Mata-Falcón, J., & Kaufmann, W. (2018). *Rethinking reinforcement for digital fabrication with concrete*. *Cement and Concrete Research*, 112, 111-121.



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9. Asprone, D., Auricchio, F., Menna, C., & Mercuri, V. (2018). *3D printing of reinforced concrete elements: Technology and design approach*. Construction and Building Materials, 165, 218-231.

8. Eventuali progetti di ricerca finanziati in cui l'attività si inserisce

- TOMORROW: TOpology & Material Optimization using additive manufactuRing to maximize stRuctural and thermal perfOrmances of building Walls
- Collaboration projects with companies (HeidelbergCement, ENEL green power, Master Builders Solutions);
- International Academic networks. International Academic networks

9. Eventuali fondi disponibili a supporto dell'attività del dottorando (escluso finanziamento borse)

- TOMORROW: TOpology & Material Optimization using additive manufactuRing to maximize stRuctural and thermal perfOrmances of building Walls
- Collaboration projects with companies (HeidelbergCement, ENEL green power, Master Builders Solutions);
- International Academic networks. International Academic networks

10. Informazioni relative ad un periodo di ricerca all'estero (minimo tre mesi) previsto per il dottorando (indicare Università/ente di ricerca e docente/ricercatore di riferimento con indirizzo mail) (max 300 parole)

ETH Zurich: Dr. Jaime Mata Falcón (mata-falcon@ibk.baug.ethz.ch), senior assistant, Chair for Structural Concrete and Bridge Design, Institute of Structural Engineering, Swiss Federal Institute of Technology (ETH) Zurich. He has recently collaborated to the National Centre of Competence in Research (NCCR) Digital Fabrication which



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aims to revolutionize architecture and engineering through the seamless combination of digital technologies and physical building processes. Over 60 researchers from six different academic disciplines collaborate to develop ground-breaking technologies for tomorrow's construction. Their research allowed ETH to take a leading position within the global field of digital fabrication.

The PhD student will spend his period at ETH (6 months in the third year) to model steel-concrete interactions in concrete elements produced by layered extrusion with a robotic arm. The goal is to define optimal fabrication options to achieve desired performances in terms of strength and ductility in beams and columns.

TU Munich: *Prof. Freek Bos* is Group Leader Additive Manufacturing of Concrete by Extrusion Process in the TUM School of Engineering and Design Technical University of Munich. His research is in the area on 3D Concrete Printing (3DCP). Freek's key interests include structural behavior of printed concrete during printing, structural behavior of printed concrete after printing in relation to print parameters, achieving structural ductility in printed concrete, and additive manufacturing processes for concrete in general. In the course of Freek's research, two reinforcement concepts have been developed that appear very promising: on-line addition of reinforcement cable and 3D printable Strain-Hardening Cementitious Composites (SHCCs; collaboration with the TU Delft).

The PhD student will spend his period at TU Munich (6 months in the third year) to model steel fibers-concrete interactions in concrete elements produced by layered extrusion with a Gantry system. The goal is to define optimal fabrication options to achieve desired fiber reinforced performances in terms of strength and ductility in beams and columns.

11. Eventuali collaborazioni con imprese/aziende sul tema di ricerca (max 300 parole)

Italcementi – HeidelbergCement is an Italian company which produces cement, ready-mix concrete and construction aggregates. In 2015, 45% of Italcementi was acquired by HeidelbergCement, together forming the world's second largest cement producer. In the last 5 years, Italcementi is currently working in the field of 3D printed



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concrete materials and structures, and also participating to national events in this context of research (e.g. Milano- FuoriSalone).

Master Builders Solutions group – Italy belongs to BASF SE which is a German chemical company and the second largest chemical producer in the world. Italian BASF group is extensively working on 3D printing materials and service solutions aiming at enabling industrial additive manufacturing at scale.

Enel Green Power: Enel Green Power was founded in December 2008 inside the Enel Group to develop and manage power generated from renewable resources worldwide. Enel Green Power has plants powered by renewable resources all around the world. The company is working to set new standards in the field of sustainable energy, constantly pushing technological limits and fostering stakeholder awareness.

Etusias S.r.l. is a start-up company founded in 2019 operating in the construction sector, with the purpose of industrializing an innovative technology already protected by one patent held by the company itself. The technical solution owned by ETESIAS is an innovative approach to the fabrication of reinforced concrete (RC) members based on 3D printing technology of concrete. The company, founded by researchers of University of Naples Federico II and University of Pavia, has recently applied for achieving the University Spinoff status. At the moment, the company runs its activities at the University of Naples Federico II (Polo San Giovanni), by adopting a robotic arm suitably equipped to produce concrete structures.

Napoli, 30/06/2023

FIRMA

Costantino Menna

A handwritten signature in blue ink, appearing to read 'Menna R. Menna'.

Il presente modulo va compilato in ogni sua parte ed inviato all'indirizzo di posta elettronica phd.dist@unina.it entro e non oltre il 30/06/2023.