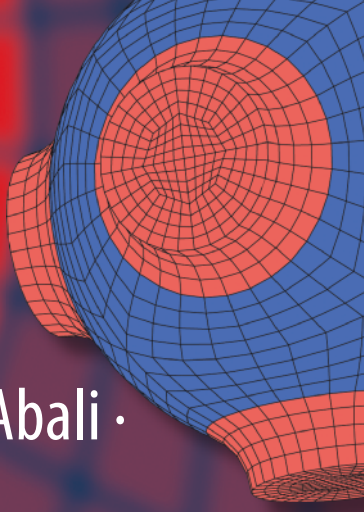
Advanced Structured Materials



Ivan Giorgio · Luca Placidi ·
Emilio Barchiesi · Bilen Emek Abali ·
Holm Altenbach *Editors*

# Theoretical Analyses, Computations, and Experiments of Multiscale Materials

## A Tribute to Francesco dell'Isola

Springer

# Advanced Structured Materials

Volume 175

Common engineering materials are reaching their limits in many applications, and new developments are required to meet the increasing demands on engineering materials. The performance of materials can be improved by combining different materials to achieve better properties than with a single constituent, or by shaping the material or constituents into a specific structure. The interaction between material and structure can occur at different length scales, such as the micro, meso, or macro scale, and offers potential applications in very different fields.

This book series addresses the fundamental relationships between materials and their structure on overall properties (e.g., mechanical, thermal, chemical, electrical, or magnetic properties, etc.). Experimental data and procedures are presented, as well as methods for modeling structures and materials using numerical and analytical approaches. In addition, the series shows how these materials engineering and design processes are implemented and how new technologies can be used to optimize materials and processes.

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*A tribute to Francesco dell'Isola, a visionary scientist of the 21th century*

# Preface

We believe ourselves to be incredibly lucky to be co-workers of Francesco dell'Isola, whom each of us met in different periods of their lives. We all have in common the fact that, soon after meeting him, we understood that he is a unique scientist, not only because of his extremely wide knowledge and erudition, but also because of his illuminating presence among his students and colleagues: Francesco dell'Isola knows that teamwork is crucially important in science. While he is always busy doing something scientifically, he puts much effort into inspiring new students as well as in helping to create ingenious connections between people.

The workshops that he organizes in Arpino, where one is allowed to interrupt the speaker to discuss any single point—the devil is in the details, after all—and where the time schedule has not to be strictly followed (like Italian trains do!), have definitely determined some of the recent research lines in theoretical and applied mechanics. Such gatherings lead to establishment of many international research collaborations. Therefore, we can confidently state that Francesco dell'Isola is a true influencer of contemporary continuum mechanics. We dedicate this book to him on the occasion of his 60th birthday, with the wish of continuing in his activities for many more years, full of energy and curiosity.

L'Aquila — *Ivan Giorgio*
Rome — *Luca Placidi*
Sassari — *Emilio Barchiesi*
Stockholm — *Bilen Emek Abali*
Magdeburg — *Holm Altenbach*

**Fig. 1** Francesco dell'Isola with Richard Toupin, 4th Canadian Conference on Nonlinear Solid Mechanics, Montreal, July 2013

**Fig. 2** Francesco dell'Isola is in action as a hobby photographer in Sora, province of Frosinone

# Foreword

There are a lot of things that would be worth saying about Francesco and his scientific and academic activity. Here I prefer to spend just a few words about a quality that, although it could seem of minor interest, in my opinion, deserves to be stressed.

I dare say that (at least) in the Italian Academic Community, among appreciate scientists, there are not many that are really able to teach something to someone. And also between them there is a very limited number, quite exceptions, that can be defined (using a Latin word) magister, that is a scientist able not only to teach something to students but also to act as a real guide and mentor in research and life for them. They can be distinguished from the others as having not only a strong culture but also the ability to foster their students to develop autonomy, maturity, critical sense and open mindedness, being also able to really help them to grow and find a way as men/women as well as researchers.

This can be done in many ways even though a necessary condition is to encourage and help students to interact, as far as possible, with other distinguished researchers as, following Goffredo Fofi, it can be said that

> (only) the bad teacher do not tolerate that their pupils could have other mentors, even though no eminent teacher ever had only one teacher in his life.

With this in mind I think that Francesco, without any doubt, can be defined a good teacher or, better, a magister.

Rome *Nicola Luigi Rizzi*

**Fig. 3** Francesco dell'Isola with Emilio Turco, Rome, January 2021

**Fig. 4** Lesson on Cyclopean Wall at Arpino, 2019

## Francesco dell'Isola: Scholar, Scientist, Historian, Philosopher

I am delighted to have the opportunity to present to my dear friend and valued colleague, Francesco dell'Isola, this collection of papers, authored by many of his friends and admirers, on the occasion of his 60th birthday.

Francesco is quite literally the glue that binds together a far-flung community of mechanicians, mathematical physicists, and engineers that spans the globe. Thus has emerged the dell'Isola School, concerned with real-world applications of topics such as strain-gradient elasticity, homogenization of lattice-like substructures, fabric materials, and theories of $n$-th grade continua, once regarded as esoterica, but now, thanks largely to Francesco's efforts, playing a central role in the understanding, modeling, and design of the advanced mechanical metamaterials so crucial to emerging technologies. Francesco dell'Isola is a person of unusually deep culture and a great aficionado of history. Thanks to his tireless efforts in translating the great works of G. Piola from 19th century Italian to modern English, the international community now has access to a profound corpus of thought on the foundations of mechanics that, remarkably, presages much of what is now viewed as the most compelling aspects of modern research.

All who have had the good fortune to interact with Francesco dell'Isola know him as a devoted mentor and protector of promising young scientists. His efforts in founding the M&MOCS center (Mathematics and Mechanics of Complex Systems), and the prestigious journal of the same name, have yielded a most auspicious milieu in which young talent can thrive and flourish.

I extend my thanks and best wishes to Francesco dell'Isola for his friendship and guidance, and for setting such a fine example of dedication and devotion to our subject.

Berkeley *David Steigmann*

**Fig. 5** At UC Berkeley with a view over the bay and the Golden Gate Bridge, 2018

**Fig. 6** Pantographic structures get broken, too, sad but true!

It is a pleasure and honor to write this birthday message for Francesco dell'Isola—a colleague, a guide, and a friend. As he reaches a significant juncture in his life journey, Francesco has substantial accomplishments that are worthy of celebration. I am certain he will be kind enough to indulge us in this felicitation. His contributions in continuum mechanics are well known and formidable. One simply has to look at his scholarly contributions to understand the breadth and depth of his impact on contemporary continuum mechanics. The following quote from Gerard Maugin's work on developments in continuum mechanics says volumes:

> "Presently, the most active and creative contributor to our field seems to be Francesco dell'Isola (born 1962). Formed in Naples with A. Romano and true mathematician in his style of approach, his interests span many particular fields . . . " (in Continuum Mechanics through the Twentieth Century: A Concise Historical Perspective, G.A. Maugin, Springer, Dordrecht, 2013).

His investigations cover topics ranging from his early works on non-material interfaces to recent works on metamaterials and generalized continua. It is his work on second gradient continuum theories that resulted in our fortuitous and eventful meeting at a conference in California in 2010. It was immediately clear to me that my own quest would benefit with a deeper interaction with Francesco and his research group in M&MoCS. My many interactions with him have been fruitful and have resulted in many co-authored publications.

I will not catalog here the long list of topics that Francesco has researched and published. Instead, I will highlight his commitment to the field of mechanics, its history and to its growth as a fundamental mathematical science. M&MoCS and the associated journal are efforts in this direction. So are the excellent workshops and meetings with unfettered exchange in Cisterna di Latina, in Arpino, and in Guiliano di Roma. Those who have participated in these will attest to the warm hospitality of Francesco as well as recall the lessons in ancient Roman history besides the intense scientific exchanges. The breadth of Francesco's interests are astonishing and are reflected in his publications that include works on economics as well as unclassifiable work that interweaves fiction, facts, history, and mathematics; and deals with human questions.

I have personally benefited from deep deliberations with Francesco on topic ranging from Greco-Roman history, its philosophy, mathematical and scientific achievements, and medieval Italian accomplishments, current scientific questions to cultural issues. In these interchanges, Francesco's openness and ability to accept alternative viewpoints are notable. I hope that these interchanges continue so we can live up to the ideals of the ancient mantra from Rig-veda

> "आ नो भद्राः क्रतवो यन्तु विश्वत्व् अदब्धासो अपरीतास उद्भिदः| ... ||1.89.1||
>
> (May we receive noble/beneficial/munificent thoughts from all directions (every side), unaltered, unconstrained, unsubdued in every possible way. . . . (1.89.1))."

On his 60th birthday, I wish him unhindered success, perfect health, and infinite energy, such that we may continue our discussions, collaborations, and explorations on wide ranging topics.

Kansas *Anil Misra*

# Francesco dell'Isola: a μαθητικός of Magna Graecia

Emilio Barchiesi & Emilio Turco

## Biographical Sketch

Francesco dell'Isola was born in July 1962, in Naples. He graduates in Physics in 1986 at the University of Naples Federico II under the direction of Prof. Antonio Romano. Always under the direction of Prof. Romano, in 1992, he obtains the Doctorate for the research in Mathematical physics discussing a thesis entitled *Rational Thermodynamics of Nonmaterial Bidimensional Continua*. In the academic year 1991/1992 he wins a competitive selection to become Researcher in Mathematical physics at the University of Naples Federico II. Shortly after, in 1992, winner of a competitive selection for becoming Researcher in Strength of materials, he moves to the Sapienza University of Rome, where he will work with another of his Masters, Prof. Antonio Di Carlo. In 1995, he obtains the *Qualification aux fonctions de maître de conférences* in the sixtieth section (*Mécanique, génie mécanique, génie civil*) and, in 1997, becomes Associate Professor. In 2004, he takes up the role of Adjunct Associate Professor at Virginia Polytechnic Institute and State University. In 2005 he obtains the National Eligibility to the functions of Full Professor. The following year he becomes Full Professor at the Sapienza University of Rome.

In 2009 he is among the founders of the MEMOCS Research Center for Mathematics and Mechanics of Complex Systems, which since its foundation organizes every year workshops, summer schools, research weeks, prestigious conferences (Euromech Colloquia, Soriau Colloquium, ICoNSoM, ICMM, GeoMech, to name a few) and to which are affiliated more than 200 scientists from all over the world. In 2016 he moves to the University of L'Aquila, where he is also the Director of

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the MEMOCS Center, a position he still holds. Then, in 2017, he takes the role of the Director of the Research Laboratory for the problems of strength, dynamics and service life at Lobačevskij University in Nižnij Novgorod, Russia, where he is also the Principal Investigator of a project funded under the prestigious MegaGrant program. In 2018, he becomes Russell Severance Springer Professor in the Department of Mechanical Engineering at the University of California, Berkeley.

## Scientific Contributions

The scientific career of Francesco dell'Isola has been since the beginning focused on avant-garde themes. On the one hand there are the more purely theoretical studies, including early work on curved interphase interfaces, in which he began to be interested in second gradient continua, fluids in this case. The interest in second gradient theories, developed during his French period and inspired by the reading of the texts of Paul Germain, led him to write jointly with Pierre Seppecher the work *The relationship between edge contact forces, double forces and interstitial working allowed by the principle of virtual power*, published in 1995 and of considerable impact on much of the subsequent literature concerning the subject. Initially, the most applied studies concern the De Saint-Venant's Problem (addressed starting with the contribution *Outlooks in Saint-Venant Theory I: Formal Expansions for Torsion of Bredt-like sections* published in 1994), the mechanics of large ice masses (in collaboration with Kolumban Hutter, addressed from the contribution *Continuum mechanical modelling of the dissipative processes in the sediment-water layer below glaciers* published in 1997), and then turn to passive control of beams, shells, and plates through the use of distributed piezo-electric transducers, and finally to deformable porous solids, with Olivier Coussy and Felix Darve.

Francesco dell'Isola moves with incredible agility between theoretical and applicative interests. While in 2003 he registers a patent at the US Patent Office for the development of passive control systems, the problem of the synthesis of circuits analogous to structures,[1] already addressed for the development of these control systems, stimulates the first theoretical contributions in the theory of mechanical metamaterials, led by the work written with Jean-Jacques Alibert and Pierre Seppecher in 2003, *Truss modular beams with deformation energy depending on higher displacement gradients*. In this last work some ingenious examples of micro-structures are proposed which, at the macro-scale, present higher gradient effects. It becomes increasingly clear to Francesco dell'Isola that the next challenge to face, the one in which he is still engaged, is represented by the solution of the problem of synthesis of metamaterials:

[1] It is therefore no coincidence that Francesco dell'Isola, during his lectures, is used to quote a statement taken from the twelfth of The Feynman Lectures on Physics: "The same equations have the same solutions."

> Having specified a given mechanical behavior at the macro-scale, what, if any, are the micro-structures that realize it?

In this regard, the fact that he has recently coined the terminology "ontology of metamaterials" plastically gives an idea of his intellectual spirit[2] (cf. *dell'Isola, F., Barchiesi, E., & Misra, A. (2020). Naive Model Theory: Its Applications to the Theory of Metamaterials Design. Discrete and Continuum Models for Complex Metamaterials, 141.*). This new branch of mechanics should deal with the question:

> What are the constitutive equations, induced by the presence of a micro-structure, that can translate into observable behavior in reality?

To give a better understanding of what is meant by this terminology, he traces the origins of this new branch of mechanics to the arguments that lead to the conclusion that the Poisson's ratio for an isotropic, homogeneous solid has to take a value between -1 and 0.5.

## An Eclectic Scientist

At this point, as many of his colleagues and students could testify, it will not be difficult to believe that Francesco dell'Isola's lectures and scientific presentations are characterized by the fact that, often, they include quotations from and comparisons with the thought of Francis Bacon, Sextus Empiricus, Albert Einstein, Epicurus, Galileo Galilei, Antonio Gramsci, Pierre Simon Laplace, Democritus, Giambattista Vico, Immanuel Kant, Karl Popper, Archimedes, Aristotle, Plato and many others. His propensity for interdisciplinarity is not reduced to this. We can mention, among other things, that he was also involved in analyzing, by means of game theory formalism, the short and long term consequences affecting a scientific system in which merit is evaluated only on the basis of bibliometric indicators,[3] as well as the search for methods of evaluation and reward that induce virtuous behavior among researchers. We note that on this occasion he did not fail to show off his characteristic

[2] Probably cultivated since childhood by his dear uncle Luigi De Luca, professor of philosophy at a High School. In the book *Big-(Wo)men, Tyrants, Chiefs, Dictators, Emperors and Presidents. Towards the Mathematical Understanding of Social Groups* published by Springer publishing house, the dedication reads "This work is dedicated to the memory of my beloved uncle Luigi De Luca. He was Professor of Classical Languages— Grammar and Literature and Principal of High Schools and transmitted to many generations of students the pleasure of understanding the logic intrinsic in reality. He was capable to explain to everybody, in a precise and rigorous way, every abstract idea, even the most difficult. He has taught me nearly every concept which I later needed in my scientific career, including the basics of set theory. I will never forget his lecture about Giambattista Vico, where he let me understand Vico's dream of transforming history into the phenomenological evidence predicted by A New Science (Una Scienza Nuova). I hope that his pedagogical spirit will revive in this work."

[3] Eight years after the writing of the work in which his thoughts on the subject are reported, we can say that his theory has not yet been falsified.

irony which, at times, is also expressed in his professional and intellectual life. His considerations about the above mentioned problem are in fact collected in an article, never published by any publishing house but not for this lacking of interesting contents, *A difficult problem for artificial intelligence: how to assess originality of scientific research and the dangers of apostrophes in family names*,[4] written in collaboration with his co-authors Francesco dell'Isola, Francesco D. Isola, and Francesco dellìIsola. Among his many interests, there is the one, not unusual for a physicist, for the new technologies, believing that they are not only a useful scientific product, but also, if not especially, a means to facilitate scientific progress. To this end, he has always wanted to equip himself with cutting-edge tools, from photographic tools—he is passionate about photography and related problems in optics—to computers, passing through 3D printers, which he was among the first to use to produce prototypes of mechanical metamaterials.

As it is now clear, Francesco dell'Isola has a broad interest. What is common to the intellectual activities to which he dedicates himself, is his effort in facing them always in a rational way, even when their object does not fall among the themes typically familiar to a mathematical-physicist. In this regard, it is worth mentioning that, recently, Francesco dell'Isola has published the scientific popularization book *Big-(Wo)men, Tyrants, Chiefs, Dictators, Emperors and Presidents. Towards the Mathematical Understanding of Social Groups*, whose intent is manifestly to try to apply the rationality typical of Lagrangian Mechanics also to the study of social behaviors of groups formed by human beings:

> Modern Science, evolved from Hellenistic Science, is the tool which humans have invented to understand all natural phenomena. Scientific activity is based on the formulation of mathematical models, which "mimic" natural systems. Using mathematical model one gets the solution of some "problems" which allow for the prediction and control of natural phenomena.
>
> In this book we try to present, in a friendly way, the mathematics which governs the dynamics of social groups: it has some aspects in common with the mathematics used to describe the behaviour of Lagrangian Mechanical systems! This similarity may attract the layman who has the curiosity to understand the intrinsic unity of natural phenomena. The reader is warned: although the scientific method has been extremely successful in the description of physical phenomena, human beings often refrain from applying it to the study of themselves as species, social groups or individuals. But human behavior is still based on specific natural laws (e.g. Darwinian selection) and the corresponding physical or psychological structures. In this work aforementioned taboo is overcome by exploiting the visionary understanding of the structure of social groups as gained by the results obtained by Le Marquis de Condorcet, Kenneth Arrow and John Nash.

In this book there is no lack of insight on animal and human psychology, as evidence of the great open-mindedness that characterizes him and, as mentioned before, does not keep him from devoting himself to areas that are not completely within the scope of his university studies. As further proof of this, Francesco dell'Isola has faced with

[4] The article, not published, is however available online at the address: https://hal.archives-ouvertes.fr/hal-01002678/document

the same style of thought, even if encoding the problem in a mathematically rigorous form, the analysis of the instability of economic markets.[5]

Having made this due introduction, in the next sections, we will not dwell on particular aspects of his professional life, even if they are very representative of the man. Rather, taking advantage of our position as privileged observers, we will try to elaborate some aspects of a more general nature that, often, as the reader will not struggle to understand, are also intertwined with his professional life.

## Teoria è Pratica!

These words (Theory is practice!) still echo in the mind of the first author. Year 2012. It was the beginning of his third semester at the Faculty of Engineering of the Sapienza University of Rome and he was in the middle of the so-called *biennio* (first two-year course), where the basic subjects are studied in preparation for the applied ones. Upon his arrival, on the first day of the course of Strength of Materials, Francesco dell'Isola gave to all students a sheet of paper with the *Osservazioni sulla scuola: per la ricerca del principio educativo* (Observations on the school: in search of the educational principle) taken from the Quaderno 12 (Notebook 12) of 1932, *Appunti e note sparse per un gruppo di saggi sulla storia degli intellettuali* (Memoranda and sparse notes for a group of essays on the history of intellectuals), by Antonio Gramsci. In that first lecture, he did not mention any topic related to the course, but, openly eschewing the desire to inform about the methods of examination and evaluation—a practice that he said encouraged a study lacking cultural foresight—he focused the attention of his speech on the following passage[6]:

> In the old school [that organized by the Casati Law, a law entered into force in 1861 in the Kingdom of Sardinia and extended, with the unification, to the whole of Italy] the grammatical study of Latin and Greek, together with the study of their respective literatures and political histories, was an educational principle—for the humanistic ideal, symbolised by Athens and Rome, was diffused throughout society, and was an essential element of national life and culture. Even the mechanical character of the study of grammar was enlivened by this cultural perspective. Individual facts were not learnt for an immediate practical or professional end. The end seemed disinterested, because the real interest was the interior development of personality, the formation of character by means of the absorption and assimilation of the whole cultural past of modern European civilisation. Pupils did not learn Latin and Greek in order to speak them, to become waiters, interpreters or commercial letter-writers. They learnt them in order to know at first hand the civilisation of Greece and of Rome—a civilisation that was a necessary precondition of our modern civilisation: in other words, they learnt them in order to be themselves and know themselves consciously.

Francesco dell'Isola strongly believes in the importance of historical knowledge: relating current problems to their historical development, often consulting the sources

[5] F. dell'Isola and A. del Monte, "Dynamic Flexibility, optimal organisation modes and price instability," Studi economici, 1995.

[6] "On Education," in Selections from the Prison Notebooks. Translated and Edited by Q. Hoare and G. N. Smith. New York: International Publishers, 1979.

directly, searching for their roots, the study of the archetype, are all elements that distinguish his scientific activity, as well as his way of approaching the study of any problem. For example, in his attempt to understand the causes underlying the current situation of Southern Italy, he cultivated his natural passion for the history of Italy, turning his attention to its unification in particular. It is not unusual to hear him talk, either during presentations at conferences or during lunch breaks, about French, Russian or Turkish history. In the area of the history of Mechanics, he has successfully analyzed the works of, among others, Archimedes, Tullio Levi-Civita, Ernst Hellinger, Erwin Schrödinger, Gabrio Piola, Giuseppe Luigi Lagrangia, Leonhard Euler, Galileo Galilei, Jean-Baptiste Le Rond d'Alembert, Archita of Tarentum, the Bernoulli brothers, Richard Toupin, Leonid Ivanovich Sedov, George Green, Heinrich Hencky, James Clerk Maxwell, William Rowan Hamilton, Vladimir Igorevič Arnol'd, Claude-Louis Navier, Augustin-Louis Cauchy, Enrico Betti, Luigi Federico Menabrea, Alberto Castigliano, relating the sources to contemporary or later knowledge.

Without neglecting philological aspects either, he sometimes confronted, with the help of colleagues, the texts in the original language, of which he provided commented translations, with original historical and scientific notes. It is worth mentioning here the two volumes *The Complete Works of Gabrio Piola: Commented English Translation*, the series of exegesis of *Fundamentals of the Mechanics of Continua* by E. Hellinger, as well as the recent book *Evaluation of Scientific Sources in Mechanics. Heiberg's Prolegomena to the Works of Archimedes and Hellinger's Encyclopedia Article on Continuum Mechanics*. With his work, over the years, he has shown that it is not unusual for valid scientific ideas to be ignored—or at best lost and eventually rediscovered more or less independently in later times—because they are written in a language inaccessible to the scientific community of interest. In other words, he argues, with numerous arguments, that the establishment of a *lingua franca* for science, as English is today and Latin and French were in the past, in addition to the obvious advantages, inevitably involves significant losses of knowledge

The reasons behind the vehemence with which the lecturer in the Construction Science course taken by the first author[7] repeated the mantra "Theory is practice!"[8] deserve to be reported explicitly. That of the lecturer was an invitation to wake up from the drowsiness and negligence with which, often not without the bad example of the faculties, the theoretical issues underlying the results of major applicative importance that are taught in engineering courses are addressed. Perpetuating and transmitting only the "know-how," clearly easier to do in the short time in which

[7] Francesco dell'Isola, thanks to the reading of a book kept in the library G. Boaga of the Faculty of Civil and Industrial Engineering of La Sapienza University of Rome, was aware of the historical facts that in the Italian pre-unitary period led to the need to call professors from Vienna and Paris to re-found the School of Engineering in Milan after the promulgation of a law that allowed to become an Engineer by just doing a few years of apprenticeship in an engineering office.

[8] This motto is also the basis of the pamphlet, which we recommend reading, "Teoria è pratica! Un saggio sul metodo scientifico con un apologo raccontato al principiante" (Theory is practice! An essay on the scientific method with an apologue told to the beginner) written by Francesco dell'Isola and published in 2008 by the Esculapio publishing house.

even degree programmes have been compressed in Italy following the introduction of the so-called "3+2 system" leads to a dangerous loss of the theoretical knowledge that generated such a "know-how." This causes, generation after generation, a progressive cultural impoverishment. Knowing how to do something, possessing the so-called "skills," as opposed to the theoretical knowledge at its base, does not allow one to generate new knowledge or to improve and adapt current knowledge in order to know how to do something tomorrow. The drift that such a society risks—if a mere economic question could help raise awareness on the issue—should make worry especially those countries like Italy that, poor in natural resources and lacking in low-cost labor, base their economy on the development of high technology. When the intellectual class, in our case the scientific one, dies out as it often happens—for different reasons—in rather more dramatic situations (dictatorships, wars, periods of economic crisis, etc.) society must necessarily import knowledge developed elsewhere. This appears critical especially in the strategic sectors of a country. Francesco dell'Isola is therefore strongly aware of the importance of his role as a teacher, and not only as a scientist, within society.

## The Scholarly Profession

The first author recalls that, continuing the reading of the above-mentioned passage from Gramsci, the teacher placed great emphasis on the sacrifice required by *true* study:

> Would a scholar at the age of forty be able to sit for sixteen hours on end at his work-table if he had not, as a child, compulsorily, through mechanical coercion, acquired the appropriate psycho-physical habits? If one wishes to produce great scholars, one still has to start at this point and apply pressure throughout the educational system in order to succeed in creating those thousands or hundreds or even only dozens of scholars of the highest quality which are necessary to every civilisation. (Of course, one can improve a great deal in this field by the provision of adequate funds for research, without going back to the educational methods of the Jesuits [known to be based primarily on discipline, coercion, and submission of the student].)

The first lecture of the Construction Science course finally concluded with the reading of the following excerpt:

> The child who sweats at Barbara, Baralipton is certainly performing a tiring task, and it is important that he does only what is absolutely necessary and no more. But it is also true that it will always be an effort to learn physical self-discipline and self-control; the pupil has, in effect, to undergo, a psycho-physical training. Many people have to be persuaded that studying too is a job, and a very tiring one, with its own particular apprenticeship—involving muscles and nerves as well as intellect. It is a process of adaptation, a habit acquired with effort, tedium and even suffering. Wider participation in secondary education brings with it a tendency to ease off the discipline of studies, and to ask for "relaxations." Many even think that the difficulties of learning are artificial, since they are accustomed to think only of manual work as sweat and toil.

The discipline and sacrifice that Francesco dell'Isola demanded from those students who really wanted to understand the reasons behind the most important results of the Science of Construction were rewarded by the fact that, in the end, they went far beyond the usual program. What a willing student received at the end of the course was a real initiation to the profession of scientist, including even knowledge of Greek philosophy, equations of mathematical physics, history of construction science, stability of dynamical systems, tensor analysis, model theory, rational mechanics, the axiomatizations of continuum mechanics, the theory of epicycles, Dedekind's construction of real numbers, the Navier–Stokes and transport equations, chaotic systems, Pareto and Nash equilibrium.

## New Generations of Scientists

The first author recalls that Francesco dell'Isola used to invite the most curious students to come to office hours, which often lasted until the evening, to talk about science in the round, including philosophy of science, epistemology and quantum mechanics, and not only strictly about the course Strength of Materials. The wide-ranging nature of his course has certainly enabled many student engineers to become "conscious" professionals, i.e. to apply practical tools with full knowledge of the underlying theoretical facts, and others to discover new cultural horizons and consciously head towards other branches of knowledge, such as philosophy, physics and mathematics. It is not a coincidence or an arbitrary choice of his that it is the Strength of Materials course that provides such a physical-mathematical vision to engineering students. In the book adopted in the course, he himself in fact writes

> Probably it is the familiarity with the various models of deformable bodies—together with the necessary ability to pass from one description to another of the same physical entity and to establish relations between such different descriptions—that makes, in general, the connoisseurs of the strength of materials simultaneously so inclined to the study of applications, to mathematical abstraction and to metaphysical discussions. Another peculiar characteristic of theirs is the tendency to extreme precision in their discourses, combined with an almost maniacal care in the choice of words used. This characteristic is easily understandable when we take into account that in the use of the various models currently employed by them it is very important, under penalty of an inextricable confusion of concepts and meanings, to distinguish, giving them different names, between different entities: the physical ones, which belong to the world of phenomena that we want to describe (the deformable bodies) and the abstract ones, which serve as a mathematical model of the first (Euler's beam, Timoshenko's beam, Cauchy's continuum). The necessary comparison between the performances of the various models explains, finally, both the mentioned tendencies to metaphysics and the need to choose different names to characterize the different mathematical entities used to describe the same physical entity.

The authors believe that Francesco dell'Isola has a high ethical vision of science and believes that in the academy, merit must emerge. Just as in a workshop, the proper selection of Disciples by the Master is of primary importance for the transmission of certain scientific ideas and, indeed, may determine their fate. Just from the analysis

of his co-authors, Francesco dell'Isola turns out to have been mentor to at least forty young scientists, many of which are now established professors and researchers in the most prestigious universities and research centers in the world. Francesco dell'Isola, in addition to being a Master, is in turn the heir of a noble tradition in physics and mathematics: among the scientific ancestors of Francesco dell'Isola, as reported by the database *The Mathematics Genealogy Project*,[9] we find scientists of the caliber of Tolotti, Levi-Civita, and Betti.

From what has been said so far, it is not difficult to believe that many promising and intellectually curious young people have been, are, and will be attracted in the future by the interaction with Francesco dell'Isola and led by him towards scientific research. As proof of his vision of science, Francesco dell'Isola was early to initiate the most deserving young people into research and allow them to benefit from all the tools necessary to enhance their abilities, regardless of their economic situation. Every year the MEMOCS Research Center welcomes in its residence professors, researchers and students of bachelor, master and doctoral degrees from all over the world, for periods of varying length. In particular, a selection is made of the most deserving and needy students among those who request access to the summer schools, university-level courses and internships offered by the MEMOCS Center, supporting the most needy among the students admitted to the courses by means of financial participation in the expenses necessary for their stay at the dormitory.

Even before the founding of the MEMOCS Center and the establishment of its laboratories, Francesco dell'Isola was among the founders of the "Tullio Levi Civita" Foundation for the development of scientific culture, which, among other things, established the "Tullio Levi-Civita" School of University Excellence. The School provided scholarships for the continuation of university studies and offered the possibility of being housed in its facilities in Cisterna di Latina. In order to prepare high school students in the Province of Latina for technical-scientific university studies, the "Tullio Levi-Civita " Foundation also promoted the creation of the Preparatory School for university studies. The activities of the Preparatory School were aimed at disseminating and strengthening the scientific culture of the students of the last two classes of high school and complete the educational path related to the teachings taught in high school through supplementary courses.

In the school years 2017/2018 and 2018/2020, Francesco dell'Isola took an active role in the organization of activities for the professional updating of high school teaching staff, as part of the project "Lincei per la scuola," involving some of the top experts in physics and mathematics in Italy. In order to encourage the scientific transmission from the old to the new generations of scientists, the MEMOCS Center has established since its foundation, at the impulse of Francesco dell'Isola, the "Tullio Levi-Civita" international prize, awarded to scientists who have distinguished themselves for their highly innovative results and who have contributed to the training of young researchers.

[9] https://www.mathgenealogy.org/

## Amarcord[10]

The second author recalls meeting Francesco dell'Isola during a coffee break at the Sperlonga summer school, organized by the latter in 2013. The previous scientific experience of the second author concerned mainly, at the time, the analysis of discrete systems, both intrinsically discrete and obtained by discretization of continuous models. Francesco dell'Isola, on the contrary, up to that time had devoted himself almost exclusively to the formulation and solution of continuous models. The second author remembers that, Francesco dell'Isola, although aware of the diversity of their points of view, was willing to discuss some scientific problems related to the analysis of the nonlinear behavior of metamaterials with pantographic microstructure. It is precisely their continuous and friendly discussions, a modern reinterpretation of the discrete-continuous disputes that cyclically occur in the history of Science, see the debate between Mach and Boltzmann, which define a fruitful scientific collaboration between the two, in which the two views are adopted in a synergistic way to better understand the mechanisms underlying the exotic behavior observed in metamaterials. To date, the second author has not found a topic about which, if ready to support a constructive contradiction, one cannot speak with Francesco dell'Isola without receiving generously valuable advice.

The second author also recalls that, passing through Rome, he and Francesco dell'Isola often met at a bar in the Rione Monti. In these meetings, where the best scientific ideas discussed by the two would take shape, Francesco dell'Isola, taking up what was said to be a habit of the famous Neapolitan mathematician Renato Caccioppoli, would expound his ideas by writing on the papery placemat of the bar. Rome was also the scene of their playful photo competition, of which both are enthusiasts.

Both authors can't help but mention, when thinking about long Roman walks, the propensity that Francesco dell'Isola has for engaging in discussions while walking. Although the authors are aware of the positive effects of this habit, they cannot fail to mention how these walks are "inflicted" on them in any weather condition and in any place in Europe!

[10] Amarcord is a 1973 Italian comedy-drama film directed by Federico Fellini. The film's title is a univerbation of the Romagnolo phrase "a m'arcôrd" (I remember). The title then became a neologism of the Italian language, with the meaning of "nostalgic revocation."

## Happy Birthday Francesco dell'Isola!

The authors hope that this contribution will do at least partial justice to what Francesco dell'Isola has transmitted to them: they cannot but be grateful to him for being his collaborators and friends. As can be seen from the information reported so far, his lively intellectual and educational activity, which began thirty-five years ago and which the authors believe earned him the appellation of μαθητικός[11] *of Magna Graecia*,[12] has received due recognition from the scientific community. Nevertheless, the authors believe that his enthusiasm and curiosity are still those, genuine, of a child and that, therefore, new fruitful studies are waiting for him. On the occasion of his sixtieth birthday, the authors wish him many more years of health and scientific successes—why not, even in other fields of knowledge—as well as a good reading of the contributions that many colleagues have dedicated to him in the disciplines that have most interested him so far.

[11] As reported in *Henry George Liddell. Robert Scott. A Greek-English Lexicon. revised and augmented throughout by. Sir Henry Stuart Jones. with the assistance of. Roderick McKenzie. Oxford. Clarendon Press. 1940*, the Greek term μαθητικός means "fond of learning" (Pl.Ti.88c)—see also the web page http://www.perseus.tufts.edu/hopper/text?doc=Perseus:text:1999.04.0057:entry=maqhmatiko/s

[12] In the introduction of his book *Big-(Wo)men, Tyrants, Chiefs, Dictators, Emperors and Presidents. Towards the Mathematical Understanding of Social Groups*, he writes "I did not try to hide my cultural roots, in writing this essay. I was educated in Magna Graecia, where a wonderful melting pot mixed Greek philosophy, Roman pragmatism, Longobard proud sense of freedom, Byzantine duplicity and culture, Arab initiative, inventive and tolerance, Normans loyalty and determination, French sophisticated traditions and sense of State, Spanish opportunism, Piedmontese administrative ideas."

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