

**XXII CONVEGNO GIMC**

**GRUPPO ITALIANO DI MECCANICA  
COMPUTAZIONALE**

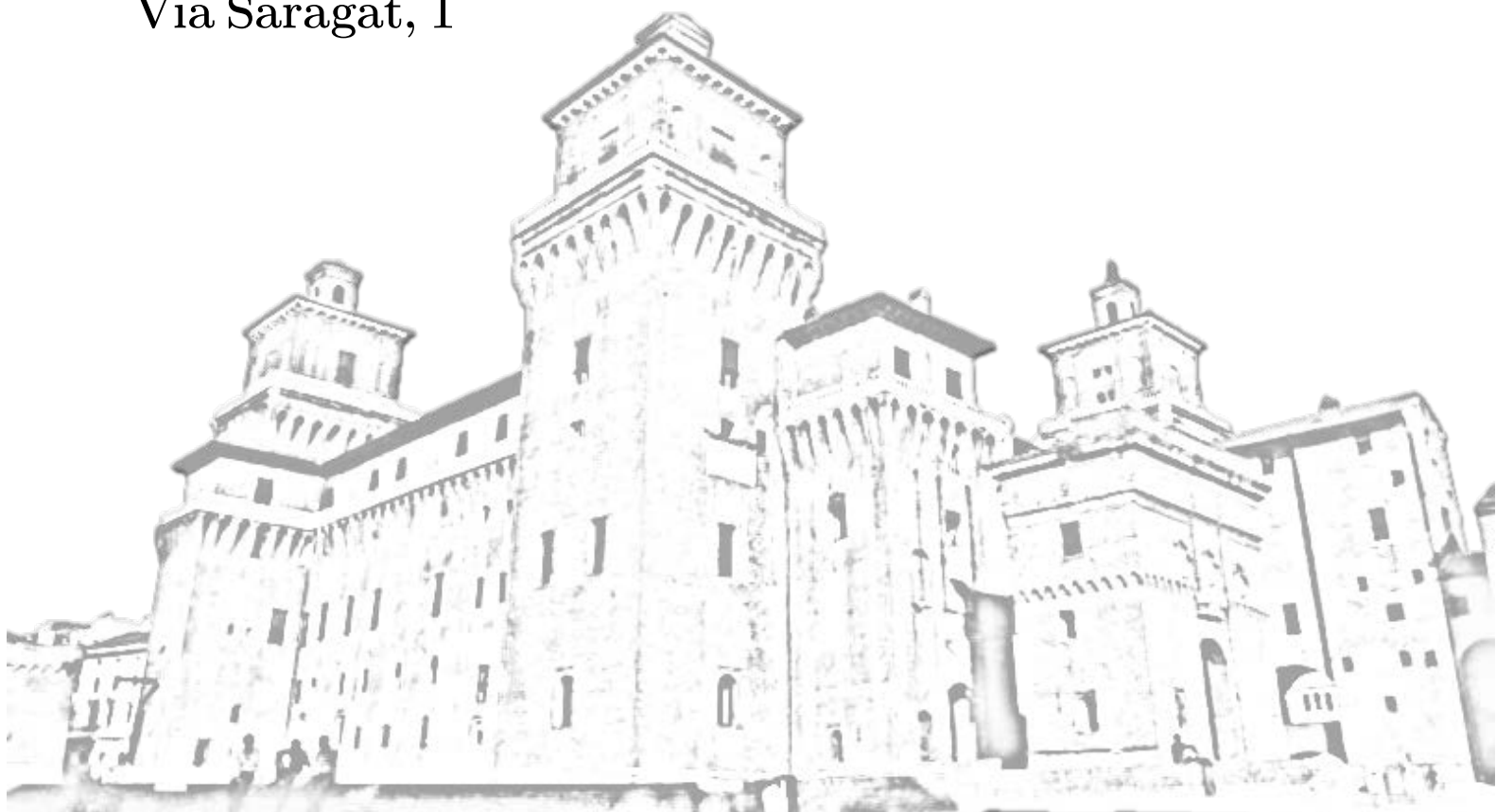
**IX RIUNIONE GMA**

**GRUPPO MATERIALI AIMETA**

**FERRARA, 13 – 14 SETTEMBRE 2018**

**DIPARTIMENTO DI INGEGNERIA**

**Via Saragat, 1**



# Table of contents

A shell finite element based on a multiscale approach for out-of-plane analysis masonry walls, Addessi Daniela [et al.]	1
Influence of Meso-Structure on the Mechanical Response of FDM 3D Printed Material, Alaimo Gianluca [et al.]	2
Multigrid algorithms for p-version Virtual Element methods, Antonietti Paola [et al.]	3
Curvilinear polygonal virtual elements for asymptotic homogenization problems, Artioli Edoardo [et al.]	4
An equilibrium-based stress recovery procedure for VEM, Artioli Edoardo [et al.]	5
A Virtual Element Method approach for 2D fracture mechanics problems, Artioli Edoardo [et al.]	6
The Virtual Element Method with curved edges, Beirao Da Veiga Lourenco [et al.]	7
Virtual Elements for the Navier-Stokes equation with application to a leaflet problem, Beirao Da Veiga Lourenco [et al.]	8
Flow and transport Virtual Element simulations in complex porofractured media, Berrone Stefano [et al.]	9
Robustness of the Stabilisation Term in the Virtual Element Method, Bertoluzza	

Silvia [et al.]	10
Inelastic analysis of framed structures with generic cross-sections, Bilotta Antonio [et al.]	11
Formulazione di un modello di delaminazione in modo misto in presenza di fiber-bridging e transizione da piccole a grandi aperture, Confalonieri Federica [et al.]	12
Closed form solution of the return mapping algorithm for three-dimensional elastoplasticity, De Angelis Fabio	13
A low-order virtual element formulation for the analysis and simulation of strain softening in solid, De Bellis Maria Laura [et al.]	14
Vulnerability curves of masonry buildings by analyses of collapse mechanisms through PR method, De Gregorio Daniela [et al.]	15
A discrete-to-continuum approach to the equilibrium of masonry vaults, De Piano Mariella [et al.]	16
Phase-field model for polarization evolution in ferroelectric materials via isogeometric collocation method, Fedeli Patrick [et al.]	17
Limit analysis and ductility check of reinforced concrete 3D frames, Garcea Giovanni [et al.]	18
Minkowski plasticity in 3D frames: geometric evaluation of the cross-section yield surface and stress update strategy, Garcea Giovanni [et al.]	19
Orthotropic macromechanical damage model for the response of masonry structures, Gatta Cristina [et al.]	20
An efficient Bbar formulation for the isogeometric analysis via Bezier projection: the case of the membrane locking, Greco Leopoldo [et al.]	21
A new conforming isogeometric multi patch formulation: the Kirchhoff shell case, Greco Leopoldo [et al.]	22

The retrofit of masonry buildings through seismic dampers, Jafarzad Eslami Babak	23
The effect of micro-polar rotation in 2D Cosserat solids, Leonetti Lorenzo [et al.]	24
Mixed Virtual Element Methods for Elasticity Problems, Lovadina Carlo [et al.]	25
Serendipity Nodal Virtual Elements, Marini Luisa	26
Isogeometric collocation for the explicit dynamics of three-dimensional beams undergoing finite motions, Marino Enzo [et al.]	27
Virtual Element Method for anisotropic materials: a constrained variational formulation for strong anisotropies in finite elasticity, Marino Michele [et al.]	28
A 3D elasto-plasto-damaged model of confined concrete composites at the mesolevel, Mazzucco Gianluca [et al.]	29
Wave propagation in curved beam structure, Meirbekova Bibinur [et al.]	30
Simulation of additive manufacturing processes: preliminary results and perspectives, Morganti Simone [et al.]	31
An isogeometric framework for erythrocyte electro-deformation simulation, Nodargi Nicola A. [et al.]	32
A regularized XFEM framework coupled to a multi-surface plasticity model for the numerical simulation of wooden structures, Orlando Nicola [et al.]	33
H(curl) finite element analysis of distortion gradient plasticity, Panteghini Andrea [et al.]	34
A thermodynamically consistent interface cohesive model for the low cycle fatigue analysis, Parrinello Francesco [et al.]	35

A three-dimensional phenomenological model for NiTi alloys describing functional fatigue and plasticity, Petrini Lorenza	36
An Efficient Virtual Element Method (VEM) Approach for Bimaterial Systems, Pingaro Marco [et al.]	37
Advanced modeling and applications of isogeometric shells, Reali Alessandro	38
Strong and Weak Formulations for the Analysis of Arbitrarily Shaped Laminated Composite Structures, Tornabene Francesco [et al.]	39
An accurate and computationally efficient phenomenological model for rate-independent hysteretic mechanical systems and materials, Vaiana Nicolò [et al.]	40
Phase-field modelling of the pseudo-ductile response of hybrid laminates, Alessi Roberto [et al.]	41
Shrinking/swelling-induced instabilities in multilayered elastic bodies, Battista Daniele [et al.]	42
A poroelastic model of bio-inspired scaffolds used for spinal fusion, Boso Daniela	43
Optimal 2D auxetic microstructures with band gap, Bruggi Matteo [et al.]	44
Phase-field modelling of cracks in variably saturated porous media with application to desiccation, Cajuhi Tuanny [et al.]	45
Passive and active remodelling of fibre reinforced hyperelastic solids, Ciambella Jacopo	46
Un approccio numerico ad elementi finiti per la simulazione di flussi granulari tridimensionali, Cremonesi Massimiliano [et al.]	47
Simulation of VEGF receptor recruitment on ECs membrane, Damioli Valentina [et al.]	48

Existence and Asymptotics for a Reaction-Diffusion-Drift Equation in the Continuum Physics of Scintillating Crystals, Davì Fabrizio	49
Variational asymptotic homogenization of slender pantographic media, Dell'isola Francesco [et al.]	50
A variational-asymptotic homogenization model for the characterization of viscoelastic materials with periodic microstructure., Del Toro Rosaria [et al.]	51
Advanced modeling of mixed-mode adhesive materials and interfaces, Dimitri Rossana [et al.]	52
Viscoelastic behaviour of polyvinyl butyral: influence of solar radiation, Fagone Mario [et al.]	53
Fracture propagation induced by gas storage operations: novel crack tracking algorithms based on a visco-plastic regularization, Fantoni Francesca [et al.]	55
Stress evaluation within nonlocal Finite Element Method, Fuschi Paolo [et al.]	56
Effective stiffness of CNT bundles under bending, Galuppi Laura [et al.]	57
A phase-field model for strain localization, Giambanco Giuseppe [et al.]	58
A variational two-phase model for micro- and macro-cracking in composites, with applications to fiber-reinforced concretes, Lancioni Giovanni [et al.]	59
Stress analysis around a tunnel in a gravitating poroelastic half plane, Lanzoni Luca [et al.]	60
Asymptotic characterization of the mechanical energy transport and acoustic wave polarization in beam lattice materials, Lepidi Marco [et al.]	61
Influence of shear and boundary conditions on the electrochemomechanics of ionic polymer metal composites, Leronni Alessandro [et al.]	62

On the role of phase segregation in the chemo-mechanical response of intercalating electrodes, Magri Marco [et al.]	63
Mixed-mode interface fracture of beam-like geometries: length scales and mode mixity angle, Massabo Roberta [et al.]	64
Un metodo Lagrangiano Esplicito per la simulazione di Problemi Tridimensionali di Interazione Fluido-Struttura., Meduri Simone [et al.]	65
Material parameter identification for the human cornea, Montanino Andrea [et al.]	66
On 2D and 3D band-gap structure in cellular locally resonant materials, Moscatelli Marco [et al.]	67
Transition waves in Rayleigh-type flexural systems, Nieves Micheal [et al.]	68
A unified variational approach to fracture in heterogeneous materials and composites, Paggi Marco [et al.]	69
A novel computational model to study complex crack paths in dynamic fracture of heterogeneous materials, Paggi Marco [et al.]	70
Numerical modelling of porous media: from freezing process kinetics to mechanical effects, Pesavento Francesco [et al.]	71
An application of variational methods in strain gradient damage and fracture mechanics, Placidi Luca [et al.]	72
H–M coupling for localized erosion phenomena in porous media, Rotunno Andrea Francesco [et al.]	73
A novel visco-plastic model for granular materials at finite strains, Salvadori Alberto	74
A degrading Bouc-Wen model with damage, Sangirardi Marialuigia [et al.]	75

Phononic materials for the passive control of Bloch waves, Vadalà Francesca [et al.]	76
Spectral decomposition for the constitutive modeling of distributed fiber-reinforced tissues, Vasta Marcello [et al.]	77
Dynamical loading on anisotropic soft anisotropic materials and tissues, Vena Pasquale	78
On a singular-value multiplicity problem arising in H <sub>infty</sub> -norm based optimization of forced dynamic systems, Venini Paolo	79
Tailoring physical and geometric properties of ionic polymer metal composites toward optimised compressive sensing, Volpini Valentina [et al.]	80
Enhanced micromorphic modelling of beam lattice: a 1D introductory approach, Bacigalupo Andrea [et al.]	81
A FE-BIE coupled method for the static analysis of beams on 3D half-space, Baraldi Daniele [et al.]	82
Three-leaf brick masonry walls: FE & DE models, Baraldi Daniele [et al.]	83
An eXtended Virtual Element Method for the Laplace problem with strong discontinuities and vertex singularities, Benvenuti Elena [et al.]	84
Multiple strain localization and debonding failure mechanisms of thin quasi-brittle coatings, Borino Guido [et al.]	85
Snap-back mechanisms of planar rods subject to kinematical boundary conditions, Cazzolli Alessandro [et al.]	86
Damage and Plasticity Model for Strain Gradient Materials and numerical applications, Cuomo Massimo [et al.]	87
Canonical quasicrystalline waveguides, Gei Massimiliano [et al.]	88



Dynamic modelling of a gyroscopic stabilizer for the flutter performances of a long span bridge deck, Giaccu Gian Felice [et al.]	89
Meta-heuristic algorithms for the kinematic NURBS-based limit analysis of curved masonry structures, Grillanda Nicola [et al.]	90
Quasi-mosaic crystals and their applications in modern research, Guidi Vincenzo	91
An isogeometric integral continuum damage approach, Mallardo Vincenzo [et al.]	92
Effective properties of composites containing toroidal inhomogeneities, Radi Enrico [et al.]	93
Experimental study on mechanical properties of NFRCM using various matrices and validation by X-Ray micro tomography., Olivito Renato [et al.]	94
Cross section reduction upon constant intrados stress in curved beams, Strozzi Antonio [et al.]	95
Numerical analyses of a URM chimney damaged by the 2012 Emilia (Italy) earthquake, Tralli Antonio [et al.]	96
Solution of XFEM ill-conditioned systems by penalty stabilization and a novel iterative procedure, Ventura Giulio [et al.]	97
Design and experimental validation of an auxetic phononic crystal for industrial micro-systems, Zega Valentina [et al.]	98
Author Index	99

---

## An eXtended Virtual Element Method for the Laplace problem with strong discontinuities and vertex singularities

Elena Benvenuti<sup>1</sup>, Andrea Chiozzi<sup>1</sup>, Gianmarco Manzini<sup>2</sup>, N. Sukumar<sup>3</sup>

<sup>1</sup>*Department of Engineering, University of Ferrara, Ferrara, Italy.*

<sup>2</sup>*T-5 Group, Los Alamos National Laboratory, Los Alamos, New Mexico, USA.*

<sup>3</sup>*Department of Civil & Environmental Engineering, University of California, Davis, USA.*

*E-mail: elena.benvenuti@unife.it, andrea.chiozzi@unife.it, gmanzini@lanl.gov, nsukumar@ucdavis.edu.*

*Keywords:* virtual element method; extended finite element method; singularities.

The Virtual Element Method (VEM) [1] directly emanates from the Mimetic Finite Difference Method and can be regarded as a generalization of the Finite Element Method, that is capable of dealing with very general polygonal or polytopal meshes. The fundamental feature of VEM is the introduction of a suitable projector operator which approximates the bilinear form characterizing the weak formulation of the continuous problem, so that the explicit construction of the elemental basis functions can be avoided. The VEM has recently aroused significant interest also in structural mechanics, where it has been applied, among others, to linear and finite elasticity problems [2-3]. In particular, polygonal and polytopal meshes can be especially suited to complex domains, such as those occurring in bodies with cracks or re-entrant corners. Unfortunately, such problems involve additional difficulties due to the existence of discontinuities and singularities in the unknown fields. In the last decades, this issue has been successfully addressed by the eXtended Finite Element Method (XFEM) [4,5], which relies on the enrichment the approximation space by means of additional shape functions specifically tailored to reproduce the non-smooth features of the expected solution.

This contribution aims to investigate the capability of VEMs to approximate solutions with jump discontinuities and vertex singularities for the Laplace problem. This goal is achieved by enriching the virtual element function space with suitable additional basis functions. The advantages of the proposed eXtended VEM will be discussed through representative numerical examples.

### *References*

- [1] Beirao da Veiga, L., Brezzi, F., Cangiani, A., Manzini, G., Marini, L.D. and Russo, A., “Basic Principles of Virtual Element Methods”, *Mathematical Models and Methods in Applied Sciences*, **23**, 119-214, 2013.
- [2] Beirao da Veiga, L., Brezzi, F. and Marini, L.D., “Virtual Elements for linear elasticity problems”, *SIAM Journal on Numerical Analysis*, **51**, 794-812, 2013.
- [3] Chi, H., Beirao da Veiga, L. and Paulino, H., “Some basic formulations of the Virtual Element Method (VEM) for finite deformations”, *Computer Methods in Applied Mechanics and Engineering*, **318**, 148-192, 2017.
- [4] Moës, N., Dolbow, J. and Belytschko, T., “A finite element method for crack growth without remeshing”, *International Journal for Numerical Methods in Engineering*, **46**, 131-150, 1999.
- [5] Tabarraei, A. and Sukumar, N., “Extended finite element method on polygonal and quadtree meshes”, *Computer Methods in Applied Mechanics and Engineering*, **197**, 425-438, 2008.