SER4SC

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES
CONFERENCE PROCEEDINGS

1st to 3rd February 2018
University of Catania
Department of Civil Engineering and Architecture

EDITORS
Giuseppe Margani
Gianluca Rodonò
Vincenzo Sapienza

EdicomEdizioni

DICAR
Dipartimento Ingegneria Civile e Architettura

UNIVERSITÀ degli STUDI di CATANIA

PROCEEDINGS OF THE

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES

SER4SC

INTERNATIONAL CONFERENCE
CATANIA, FEBRUARY 1-3, 2018

Edited by
Giuseppe Margani
Gianluca Rodonò
Vincenzo Sapienza

EdicomEdizioni

Published by EdicomEdizioni

Monfalcone (Gorizia)
Tel. 0481 484488
Fax 0481 485721
e-mail info@edicomedizioni.com
www.edicomedizioni.com

ISBN 978-88-96386-56-9

Patrons

Friends

Organizing Committee

Stefano Cascone • Dario Distefano • Melania Lombardo • Manuela Marino
Giuseppe Margani • Attilio Mondello • Gianluca Rodonò • Vincenzo Sapienza

Scientific Committee

Giuseppe Alaimo	*University of Palermo*	*Italy*
Salvatore Caddemi	*University of Catania*	*Italy*
Carlo Caldera	*Politecnico di Torino*	*Italy*
Ivo Caliò	*University of Catania*	*Italy*
Santi Maria Cascone	*University of Catania*	*Italy*
Amir Causevic	*University of Sarajevo*	*Bosnia-Herzegovina*
Massimo Cuomo	*University of Catania*	*Italy*
Giuliano Dall'Ò	*Politecnico di Milano*	*Italy*
Pietromaria Davoli	*University of Ferrara*	*Italy*
Marco D'Orazio	*Università Politecnica delle Marche*	*Italy*
Valter Fabietti	*University of Chieti-Pescara*	*Italy*
Giovanni Fatta	*University of Palermo*	*Italy*
Corrado Fianchino	*University of Catania*	*Italy*
Alberto Fichera	*University of Catania*	*Italy*
Marco Filippi	*Politecnico di Torino*	*Italy*
Luca Finocchiaro	*Norwegian University of Science and Technology*	*Norway*
Emil-Sever Georgescu	*Nird Urban-Incerc*	*Romania*
Aurelio Ghersi	*University of Catania*	*Italy*
Riccardo Gulli	*University of Bologna*	*Italy*
Paolo La Greca	*University of Catania*	*Italy*
Rosario Lanzafame	*University of Catania*	*Italy*
Raffaella Lione	*University of Messina*	*Italy*
Paulo B. Lourenço	*University of Minho*	*Portugal*
Giuseppe Margani	*University of Catania*	*Italy*
Luigi Marletta	*University of Catania*	*Italy*
Emanuele Naboni	*The Royal Danish Academy of Fine Arts*	*Denmark*
Maurizio Nicolella	*University of Naples Federico II*	*Italy*
Masa Noguchi	*University of Melbourne*	*Australia*
Francisco Hipólito Ojalvo	*University of Extremadura*	*Spain*
Luis Palmero Iglesias	*Universitat Politècnica de València*	*Spain*
Emilio Pizzi	*Politecnico di Milano*	*Italy*
José Ignacio Sánchez Rivera	*University of Valladolid*	*Spain*
Antonello Sanna	*University of Cagliari*	*Italy*
Angelo Salemi	*University of Catania*	*Italy*
Adolfo Santini	*Mediterranea University of Reggio Calabria*	*Italy*
Vincenzo Sapienza	*University of Catania*	*Italy*
Enrico Spacone	*University of Chieti-Pescara*	*Italy*
Marius Voica	*Ion Mincu University*	*Romania*

Introduction to the Conference Proceedings

1-3 February 2018, University of Catania, Catania, Italy

One of the main challenges of the twenty-first century is to increase the sustainability level of our cities.
This requirement is mostly associated to environmental issues, and a great effort has been made in the past years to build a low-carbon society. However, a town, to be considered sustainable, must, above all, be safe, particularly against natural hazards, which in Europe are mostly related to climate changes (e.g., hurricanes, floods, storms, and landslides) and seismic events (earthquakes). Unfortunately, sustainability is still not a prerogative of most European cities, especially those placed in seismic countries such as Italy, where at least 50% of the residential stock is earthquake-prone, while over 80% of the same stock is highly energy-consuming and carbon dioxide-emitting, thus contributing to trigger hazards related to climate changes. In this context, renovation actions, which combine both energy and seismic issues, are strongly needed. This assumption has to be promoted for the following main reasons: energy renovation alone will be worthless if an earthquake destroys the building; to prevent life losses and damages; to avoid several costs otherwise duplicated (costs for building-site setup and scaffolds, claddings, plasters and other finishings, etc.).
Nevertheless, several barriers considerably limit the real possibility to extensively undertake combined retrofit actions, especially for multi-owner housing and high-rise buildings. These barriers are of different kinds: (i) technical (e.g., unfeasibility and/or ineffectiveness of conventional retrofit solutions, and need of regulatory simplification); (ii) financial (e.g., high renovation costs, "split-incentive"/"landlord–tenant dilemma", and insufficient incentives and subsidies); (iii) organizational (e.g., temporary alternate accommodation for occupants, consensus to the retrofit expenditure by condominium ownerships, and excessive time to obtain building permits); and (iv) cultural/social (insufficient information and skills, and lack of adequate policy measures to promote renovation actions).
The Seismic and Energy Renovation for Sustainable Cities - SER4SC 2018 Conference, held in Catania, 1st to 3rd February, aims to overcome these barriers and to bridge the gap between sustainability and safety, with a link that may conserve both human and environmental resources.
This edition contains 56 papers arranged by theme into 6 thematic sessions.
Each submission received reviews from at least two different Scientific Committee members and we would like to express our thanks to all the reviewers that provided detailed comments and feedback on all the submitted papers.
The selected papers were organized into sessions for the oral presentation, according to the key topics of the conference.

1st Session

Urban vulnerability and sustainable cities
Sustainability and safety of cities. Description of the vulnerability and/or energy performance scenario of any region or town. Tools and methods for assessing the urban vulnerability to natural hazards and for determining the scale of intervention to adequately reduce this vulnerability. Cost evaluation for the improvement of the urban resilience to natural hazards. Scenarios of possible financial incentives.

Resolution of organizational and practical problems
Strategies to overcome different organizational and practical problems, which considerably limit the real possibility to undertake retrofit actions, especially for multi-owner housing and high-rise buildings: consensus to the retrofit expenditure by condominium ownerships, excessive duration of renovation works and temporary alternate accommodation for occupants, split-incentive/landlord-

tenant dilemma, excessive time for getting construction permits, need of regulatory simplification, etc.

Economic and financial policies to promote renovation measures
Economic and financial tools, measures and policies to promote renovation activities.

Strategies for promoting the social sensitivity to prevention actions
Development of new policies to promote the awareness of the disastrous consequences of inadequate or insufficient prevention actions. Strategies to disseminate, among interested stakeholders, technical skills and competences on retrofitting measures, as well as to highlight the economic convenience of undertaking combined seismic and energy renovations. Training activities.

2nd Session

Construction techniques of historic and recent buildings
Description of construction techniques adopted for historic buildings (i.e. built before 1950) and recent buildings (i.e. built from the 1950s to the 1980s). Relationships between construction techniques and seismic or energy performance of buildings.

3rd Session

Seismic and energy regeneration strategies at district and urban scale
Urban regeneration strategies for the reduction of seismic vulnerability and/or energy dependence. Integrated land use and transport planning to reduce energy consumption due to private means of transportation.

4th Session

Design, monitoring and management tools
Novel tools for design, monitoring and management of existing buildings (e.g. BIM, parametric design, form finding, sensor grids, building management systems, etc.), with particular reference to renovation and post-renovation activities.

Retrofit optimization through prefabricated systems
Development of prefabricated systems to accelerate seismic and/or energy renovation activities, in order to reduce costs and inconvenience to the occupants.

5th Session

Technical solutions, materials and methods for seismic and energy renovation
Technical solutions, materials and methods for the seismic and/or energy renovation of historic and/or recent buildings.

6th Session

Decision support tools for the selection of the optimal retrofitting scenario
Development of user-friendly decision support tools to select the best seismic and/or energy renovation scenario, in terms of effectiveness, efficiency, costs, available incentives and subsidizes, safety, inconvenience to the occupants, etc.10. Resolution of organizational and practical problems.

Diagnostic techniques and numerical models to assess seismic vulnerability and energy performance
Development of novel diagnostic techniques and numerical models to determine the seismic vulnerability and/or the energy performance of historic and/or recent buildings.

Despite the different disciplines and viewpoints represented at the conference, all participants agreed that the challenge of combining energy renovation actions ad seismic upgrades are urgent and represents today a prevention action that is becoming more and more necessary to increase the sustainability level of our towns.
Seismic and energy renovation of buildings will allow reaching very relevant benefits, at environmental, social and economic levels.
Consequently, wide engagement actions, at both local and European level, are fundamental to raise awareness of the social, environmental and cultural relevance of prevention actions, and to achieve consensus and behavioural change towards decisional strategies for both energy efficiency and seismic safety.
Prevention is essentially a matter of mindset and culture. Since European countries have a great tradition and culture, the basic premises for developing a prevention attitude are all there.
In this context, schools, universities and research institutes play a crucial role, stimulating institutions and political forces to strongly promote the upgrade of the building stock.
This virtuous circle is possible, as well shown by the movement for the restoration of historic cities that has originated in Europe and afterwards has reached brilliant results of urban rebirth, which are clearly evident in Italy as well as in many other countries
This conference has engaged expertise and experiences of scientists, scholars, professionals and decision-makers from different countries, in order to find new effective, affordable and holistic solutions, which may positively contribute to enhance the sustainability level of our towns. In other words, this conference has aimed to become a hub, where people can discuss and start developing new robust renovation strategies for sustainable cites.

Acknowledgements:

We would like to thank our sponsors for their invaluable help for the success of the conference. We especially thank the Department of Civil Engineering and Architecture of the University of Catania (DICAR), the Order of the Engineer of Catania, the Foundation of the Engineer of Catania, the National Association of Building Constructors of Catania (ANCE Catania) for their attention to the issue of sustainable urban renovation, and their action of spreading the culture of risk mitigation.

Giuseppe Margani
Vincenzo Sapienza
Gianluca Rodonò

Contents

Introduction

1st Session

14 TOPIC: Urban vulnerability and sustainable cities

15 ASSESSING AND MANAGING SEISMIC RISK IN OLD URBAN CENTRES
José L.P. Aguado, Tiago Miguel Ferreira and Paulo B. Lourenço

24 ASSESSING URBAN AND BUILDING VULNERABILITIES CONNECTED TO THE EMERGENCY MANAGEMENT: AN INTEGRATED METHODOLOGY
Martina Zorzoli, Giovanni Metelli, Michèle Pezzagno, Giovanni Plizzari and Roberto Busi

35 COLLECTIVE SOCIALIST HOUSING IN ROMANIA – COMPLEX SOLUTIONS FOR SUSTAINABLE UPGRADE, BETWEEN/BESIDES ENERGY IMPROVEMENT AND STRUCTURAL SAFETY
Zina Macri

44 SUSTAINABLE ENERGY ACTION PLANS: MONITORING THE IMPLEMENTATION OF STRATEGIES FOR SUSTAINABILITY FOR MUNICIPALITIES IN NORTHEN ITALY
Giuliano Dall'O', Luca Sarto, Alberto Pizzi and Sandro Cristina Reggiani

57 A SIMPLIFIED MODEL BASED ON SELF-ORGANIZED CRITICALITY FRAMEWORK FOR THE SEISMIC ASSESSMENT OF URBAN AREAS
Annalisa Greco, Alessandro Pluchino, Luca Barbarossa, Ivo Caliò, Francesco Martinico and Andrea Rapisarda

69 A SIMPLIFIED METHODOLOGY TO ASSESS SEISMIC RISK AT DISTRICT AND BUILDING LEVEL
Ivo Caliò, Rosa Caponetto, Chiara Ciatto and Daniele La Rosa

82 HOSPITAL SAFETY IN SPATIAL AND URBAN PLANNING AND DESIGN–SEISMIC ZONE IN THE KOLUBARA REGION IN SERBIA
Borjan Brankov, Marina Nenković-Riznić, Mila Pucar and Snežana Petrović

92 TOPIC: Resolution of organizational and practical problems
Economic and financial policies to promote renovation measures
Strategies for promoting the social sensitivity to prevention actions

93 SEISMIC AND ENERGY RENOVATION MEASURES FOR SUSTAINABLE CITIES: A CRITICAL ANALYSIS OF THE ITALIAN SCENARIO
Paolo La Greca and Giuseppe Margani

105 A EUROPEAN PROJECT FOR SAFER AND ENERGY EFFICIENT BUILDINGS: PRO-GET-ONE (PROACTIVE SYNERGY OF INTEGRATED EFFICIENT TECHNOLOGIES ON BUILDINGS' ENVELOPES)
Annarita Ferrante, Giovanni Mochi, Giorgia Predari, Lorenzo Badini, Anastasia Fotopoulou, Riccardo Gulli and Giovanni Semprini

117 RESILIENCE, PREPAREDNESS AND SCENARIO EXERCISES: POTENTIALITIES AND WEAKNESSES OF DRR EDUCATION STRATEGIES
Mara Benadusi

2nd Session

128 TOPIC: Construction techniques of historic and recent buildings

129 PROJECTS AND CONSTRUCTION TECHNIQUES IN POST-SEISMIC RECONSTRUCTIONS AT THE BEGINNING OF THE TWENTIETH CENTURY
Cesira Paolini and Marina Pugnaletto

141 THE BUILDING INFORMATION MODELING FOR THE RETROFITTING OF EXISTING BUILDINGS. A CASE STUDY IN THE UNIVERSITY OF CAGLIARI
Giuseppe Desogus, Giuseppe Martino Di Giuda, Giuseppina Monni, Emanuela Quaquero, Antonello Sanna, Lavinia Chiara Tagliabue and Valentina Villa

151 ROLE OF SKY GARDENS IN IMPROVING ENERGY PERFORMANCE OF TALL BUILDINGS
Humera Mughal and Rossella Corrao

160 THE RESILIENCE OF TRADITIONAL ARCHITECTURE: THE ANTI-SEISMIC CONSTRUCTIVE SYSTEM OF LEFKADA ISLAND
Emilia Garda, Marika Mangosio and Angeliki Vlachou

169 OPTIMIZING ENVIRONMENTAL PERFORMANCE OF HISTORICAL BUILDINGS. THE CASE OF HOU JI VILLAGE
Luca Finocchiaro and Fu Xiuzhang

181 SEISMIC AND ENERGY REFURBISHMENT OF RESIDENTIAL BUILT HERITAGE IN MEDITERRANEAN CLIMATE
Angelo Salemi, Alessandro Lo Faro, Attilio Mondello, Angela Moschella and Giulia Sanfilippo

193 THERMAL AND ECONOMIC GREEN ROOF PERFORMANCE FOR BUILDING RETROFIT
Stefano Cascone, Federico Catania, Antonio Gagliano and Gaetano Sciuto

205 SEISMIC AND ENERGY RENOVATION, COMPARISON BETWEEN THE DESIGN APPROACH IN ITALY AND IN ROMANIA
Emil-Sever Georgescu, Mihaela Stela Georgescu, Zina Macri, Edoardo Michele Marino, Giuseppe Margani, Vasile Meita, Radu Pana, Horia Petran, Per Paolo Rossi, Vincenzo Sapienza and Marius Voica

221 PRE-MODERN ANTISEISMIC PRESIDIA IN L’AQUILA. WOODEN ELEMENTS AND CONSTRUCTION TECHNIQUES IN HISTORIC BUILDING
Alessandra Bellicoso and Alessandra Tosone

233 THE COLLAPSE OF THE TOWER OF VALLADOLID CATHEDRAL AND ITS CONTROVERSIAL RELATIONSHIP WITH THE 1755 LISBON EARTHQUAKE
Angelo Salemi, José Ignacio Sánchez Rivera, Attilio Mondello and Juan Luis Sáiz Virumbrales

3rd Session

246 TOPIC: Seismic and energy regeneration strategies at district and urban scale

247 THE COMPLEX, MULTICRITERAL RENOVATION OF HOUSING DISTRICTS. INTEGRATED CONCEPT OF PROJECTS FOR HOUSES AND CITY. RESULTS OF “SIR RESEARCH PROJECT” IN ROMANIA
Codruta Iana, Mihaela Stela Georgescu, Cristina Victoria Ochinciuc, Carmen Dumitrescu, Cerasella Craciun, Ana Opris

260 PROCEDURES FOR A QUALITATIVE ASSESSMENT OF THE SEISMIC VULNERABILITY OF HISTORICAL CENTERS. THE CASE STUDY OF ACIREALE (CT)
Chiara Circo and Anna Scudero

270 A GREEN INFRASTRUCTURE STRATEGY FOR REDUCING SEISMIC VULNERABILITY AND ENHANCING ENERGY EFFICIENCY IN URBAN CONTEXTS
Riccardo Privitera and Daniele La Rosa

282 RECOVERING THE ANCIENT HAMLET BY AN INTEGRATED ENERGY AND SEISMIC PLAN ACTION: THE CASE OF BAIA AND LATINA
Marina Fumo, Antonella Violano, Antonio Formisano and Giulia Sibilio

294 SEISMIC ASSESSMENT OF TYPICAL MASONRY HISTORICAL RESIDENTIAL BUILDINGS IN CATANIA
Salvatore Caddemi, Ivo Caliò, Giuseppe Di Gregorio, Andrea Famà, Annalisa Greco, Grazia Lombardo

306 CORRECTIVE REMEDIATION PROPOSALS FOR THE INA CASA DISTRICTS IN MESSINA (1949-1963)
Ornella Fiandaca, Raffaella Lione and Fabio Minutoli

319 EXPOSURE AND RISK REDUCTION STRATEGY: THE ROLE OF FUNCTIONAL CHANGE
Roberto De Lotto, Veronica Gazzola and Elisabetta M. Venco

4th Session

331 TOPIC: Design, monitoring and management tools

332 SUSTAINABLE LOW CO2 EMISSION RETROFIT STRATEGIES OF PUBLIC BUILDING IN MEDITERRANEAN AREA: A CASE STUDY
Manfredi Cannata, Maurizio Detommaso, Gianpiero Evola, Antonio Gagliano, Luigi Marletta, Francesco Nocera

341 CRITICAL ISSUES ON INTEGRATED SOLUTIONS FOR SEISMIC AND ENERGY RETROFITTING OF HIGH-RISE BUILDINGS IN REINFORCED CONCRETE WALLS AND PANELS: THE M4 IN TOR BELLA MONACA, ROME
Edoardo Currà, Lorenzo Diana, Emanuele Habib and Salvatore Perno

353 MULTICRITERIA ANALYSIS FOR CHOOSING MAINTENANCE STRATEGIES
Maurizio Nicolella, Claudio Scognamillo and Alessio Pino

365 OPTIMIZATION OF OUTDOOR COMFORT CONDITIONS WITH KINETIC ADAPTIVE SHELTER: THE CASE STUDY OF PIAZZA ARMERINA ARCHAEOLOGICAL SITE
Gianluca Rodonò, Emanuele Naboni, Vincenzo Sapienza, Federico Cucchi and Giacomo Macrelli

377 ANALYSIS OF FAILURE IN URBAN ENERGY DISTRIBUTION NETWORKS
Alberto Fichera, Mattia Frasca and Rosaria Volpe

389 EARTHQUAKE EARLY WARNING AND STRUCTURAL HEALTH MONITORING IN THE HISTORICAL CITY CENTRE OF CATANIA (ITALY
Salvatore Scudero, Giovanni Vitale, Luca Greco, Domenico Patanè and Antonino D'Alessandro

399 TOPIC: Retrofit optimization through prefabricated systems

400 A SMART PREFABRICATION SYSTEM FOR THE INDUSTRIALIZED CONSTRUCTION OF RESILIENT ENERGY-SAVING BUILDINGS
Luis Palmero and Graziella Bernardo

410 THE EIGHTEENTH-CENTURY ARCHITECTURES: ANTISEISMIC FRONT SOLUTIONS
Corrado Fianchino and Eleonora Vinci

420 PREFABRICATED MODULES FOR HEALTH EMERGENCY
Daniela Besana

5th Session

432 TOPIC: Technical solutions, materials and methods for seismic and energy renovation

433 TABIÀ RENOVATION FOR ALPINE REGION IN ITALY. TRADITIONAL SOLUTION AND INNOVATIVE TECHNOLOGIES INTEGRATION
Barbara Gherri, Eva Coisson and Fabio Scola

444 PRE-STRESSED TRANSLUCENT PANELS MADE OF INNOVATIVE 3D GLASS COMPONENTS DSC-INTEGRATED, FOR SAFETY AND ACTIVE BUILDING FAÇADES
Rossella Corrao

453 IMPROVING THE ITALIAN BUILDING STOCK: ENERGY RETROFIT OF A SINGLE-STOREY PUBLIC BUILDING IN SOUTHERN ITALY
Gianpiero Evola, Luigi Marletta, Paolo Girlando and Serena Tamburella

465 “SEISMIC AND ENERGY RETROFITTING” OF THE HISTORICAL CENTRES’ BUILDINGS. A CASE STUDY IN ENNA
Tiziana Basirico and Daniele Enea

477 STRUCTURE - SPACE – ENVELOPE. BUILDING SOLUTIONS TO MITIGATE URBAN HEAT ISLAND (UHI EFFECTS
Cristina Victoria Ochinciuc and Mihaela Stela Georgescu

485 RENOVATION OF SCHOOL BUILDINGS: ENERGY RETROFIT AND SEISMIC UPGRADE, IN A SCHOOL BUILDING IN MOTTA DI LIVENZA
Tiziano Dalla Mora, Maria Pinamonti, Lorenzo Teso, Giosuè Boscato, Fabio Peron and Piercarlo Romagnoni

497 SEISMIC REHABILITATION OF BUILDING STRUCTURES USING ENERGY DISSIPATION DEVICES
Gabriel Danila and Adrian Iordachescu

508 MOULD GROWTH RISK EVALUATION OF INTERNAL INSULATION SOLUTIONS IN A HISTORIC BUILDING UNDER TEMPERATE CLIMATES
Andrea Gianangeli, Elisa Di Giuseppe and Marco D'Orazio

518 SEISMIC AND ENERGY RENOVATION: AN INNOVATIVE APPROACH TO HISTORIC PRESERVATION
Ivo Caliò, Santi Cascone, Dario Distefano, Antonio Gagliano, Giuseppe Perrica, Gianluca Rodonò and Vincenzo Sapienza

530 TECHNICAL SOLUTIONS FOR SEISMIC IMPROVEMENT OF THE MASONRY BUILDINGS: STEEL GRIDS WITH PASSIVE DAMPERS AND RC PANELS WITH FRC DOWELS
Venera Simonovic, Merima Sahinagic-Isovic and Goran Simonovic

540 PARTIAL INTERVENTIONS ON THE FACADES IN THE PROCESS OF ENERGY RENOVATION OF RESIDENTIAL BUILDINGS - EXAMPLES FROM THE SERBIAN CONSTRUCTION PRACTICE
Aleksandar Rajčić, Ljiljana Đukanović and Ana Radivojević

551 SCHOOL BUILDINGS RECOVERY
Francesca Castagneto

6th Session

563 TOPIC: Decision support tools for the selection of the optimal retrofitting scenario
Diagnostic techniques and numerical models to assess seismic vulnerability and energy performance

564 TOWARDS THE DEVELOPMENT OF A DECISION SUPPORT SYSTEM (DSS FOR BUILDING RENOVATION: DOMAIN MAPPING MATRIX (DMM FOR SUSTAINABILITY RENOVATION CRITERIA AND RENOVATION APPROACHES
Aliakbar Kamari, Rossella Corrao and Poul Henning Kirkegaard

577 ENERGY IN TIME. PARAMETERS OF ENERGETIC ACTUALIZATION OF MATERIALS/COMPONENTS
Caterina Claudia Musarella

589 URBAN RESILIENCE AND DISASTER PREVENTIVE PLANNING. MANAGE THE PREPARATION TO OPTIMIZE THE RESPONSE IN HISTORICAL TOWNS
Alessandro D'Amico and Edoardo Currà

600 OPTIMAL MEASURES FOR ENERGY RETROFIT ON THE UNIVERSITY BUILDING “EX COTONIFICIO OLCESE” IN VENICE
Davide Balboni, Tiziano Dalla Mora, Alessandro Righi, Fabio Peron and Piercarlo Romagnoni

610 ITALIAN SCHOOL BUILDING TOWARD NZEB REQUIREMENTS. THE CASE OF “C. ROSSELLI” HIGH SCHOOL IN CASTELFRANCO VENETO
Giulia Masolo, Tiziano Dalla Mora, Alessandro Righi, Fabio Peron and Piercarlo Romagnoni

622 MULTI-CRITERIA METHODOLOGY TO SUPPORT DECISION MAKING CONCERNING OPAQUE ENVELOPE COMPONENTS
Alessandra De Angelis, Rosa Francesca De Masi, Maria Rosaria Pecce, Silvia Ruggiero and Giuseppe Peter Vanoli

634 RADIANT PANELS FOR OUTDOOR HEATING: THEORETICAL AND EXPERIMENTAL ANALYSIS FOR THERMAL COMFORT ASSESSMENT
Giorgio Baldinelli, Antonella Rotili and Francesco Bianchi

645 TECTONIC SUSTAINABLE BUILDING DESIGN FOR THE DEVELOPMENT OF RENOVATION SCENARIOS – ANALYSIS OF TEN EUROPEAN RENOVATION RESEARCH PROJECTS
Aliakbar Kamari, Rossella Corrao, Steffen Petersen and Poul Henning Kirkegaard

6th Session

Decision support tools for the selection of the optimal retrofitting scenario

Diagnostic techniques and numerical models to assess seismic vulnerability and energy performance

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES

Towards the development of a Decision Support System (DSS) for building renovation: Domain Mapping Matrix (DMM) for sustainability renovation criteria and renovation approaches

Aliakbar Kamari[a,b]*, Rossella Corrao[a], Poul Henning Kirkegaard[b]

[a]Department of Architecture, University of Palermo, Palermo 90128, Italy
[b]Department of Engineering, Aarhus University, Aarhus 8000, Denmark

Abstract

Future building renovation concerns more holistic perspectives related to the sustainability seen in a wider range of objectives/criteria facilitated by the renovation scenarios. In this regard, based on the studies upon existing sustainability evaluation and assessment tools carried out in previous research works, a characteristic diagram including a value map for evaluating a holistic sustainable retrofitting was developed. Further, in present paper, by reviewing the relevant literature, looking into recent European renovation research projects, the Danish SIGMA database, and investigation of a real case, a comprehensive list of renovation approaches (i.e. insulation technologies, windows replacement etc.) were classified in 26 categories. Using empirical information, this paper expands the Domain Mapping Matrix (DMM) between the recently developed criteria (18 criteria including 118 sub-criteria) and renovation approaches (26 categories including 139 alternatives). The aim is to consider how is the dependency between renovation approaches while they meet different criteria or sub-criteria, and vice versa, regarding to the selection of the criteria versus application of some possible renovation approaches. Developing Decision Support Systems (DSS) for generation of sustainable building renovation scenarios is ultimately an intricate, challenging task. The increasing complexity of decision problems regarding to the fulfilment of sustainability objectives/criteria, the growing number of subjects involved and keen competition between conflicting costs and interests make decisions-making difficult. Developing a DMM enhances the required insight for the development of an operational system for architecture of decision-makings. It has a strong effect to deal with existing complexity regarding to the large number of renovation approaches and various sustainability objectives/criteria. Added to this, the DMM can be used for understanding and tracking of the value (or added value) regarding to the other criteria (i.e. spatial quality) while the focus is on optimization of some common criteria i.e., improvement of energy efficiency or reduction of investment cost.

Selection and peer-review under responsibility of SER4SC2018 Scientific Committee.

Keywords: Sustainable Building Renovation; Decision Support System; System Architecture; Decisions Architecture; Renovation Scenarios; Domain Mapping Matrix (DMM).

* Corresponding author. Tel.: +45 3151 8280
E-mail address: ak@eng.au.dk or aliakbar.kamari@unipa.it

1. Introduction

Recent investigations into the building renovation context, including energy improvements of existing buildings, have shown an increasing attention in many European countries [1] as well as facing new large challenges [2]. It has revealed that these initiatives can often be more cost-effective than new building projects [3]. The existing building stock need to reach European Union (EU) energy and emission reduction goals. In addition to that, it is also a necessity to ensure buildings functions, technical qualities and to provide a good living environment. That means, enhancing energy efficiency is not the only goal for renovation of existing buildings. The extent of the potential for energy improvements can be described and made up in several ways [4]. This can happen with focus on climatic interests, security of supplies, environmental impacts, life-cycle cost, indoor climate, building functionality, spatial quality issues and other relevant arguments. Existing buildings can benefit from adopting a more broad approach to sustainability, which seeks to decrease operation and maintenance costs; reduce environmental impacts; and can increase the building's adaptability, durability, and resilience towards future challenges. Consequently, buildings may be less costly to operate, may growth in value, last longer, and contribute to a preferable, healthier, more convenient environment to the occupants. When all of these interventions are summated, they can move the renovation case towards the goal of overall sustainability, which demands more holistic renovation approaches.

The improvement of existing buildings involves two major steps: current condition assessment and future upgrade strategies [5]. Most of the methods focus on the first step of the improvement process, understanding or predicting energy usage but no generation of possible renovation scenarios. While the latter is about proposing of the future upgrade renovation solutions. The integrated renovation scenarios[†]/packages that can be leveraged at an existing building – and is related to possible interactions between various renovation objectives – is not taken into consideration in most retrofitting projects. The results are, therefore, suboptimal renovation solutions, which do not reach the full scope of sustainability for refurbished building(s). The major issue here can be considered as what the ultimate holistic values are and how the values are added by use of renovation alternatives. As response to this, the Danish research project RE-VALUE[‡] (Value Creation by Energy Renovation, Refurbishment and Transformation of the Built Environment, Modelling and Validating of Utility and Architectural Value) has been initiated to establish a more holistic approach to the assessment of value creation in building renovation projects. The outcomes are going to be used for development of a Decision Support System (DSS) to generate the renovation scenarios with implementation of addition of holistic criteria during early design stage. The aim is to add value to renovation projects by generating efficient renovation scenarios concentrating on sustainability objectives/criteria.

† The term "renovation scenario" used in this study means a selection and combination of some different renovation technologies/actions (i.e. insulation of the external walls or replacement of the windows are each a renovation action) that together build alternative renovation scenarios/packages and subsequently is applied in a renovation project.
‡ Participated by Brabrand Housing Association – with energy renovation in the Aarhus suburb of Gellerup – as well as DEAS, an administration company on the private rental housing market (for more info: http://www.revalue.dk)

1.1. 'System architecture' and modelling of a 'system architecture' by use of matrix-based approaches

Nowadays, renovation projects and development of the most appropriate renovation scenarios are becoming more and more complex for increasing the number expectations from a holistic renovation. In the development of renovation scenarios, considerations about involvement of various objectives, architectures and modularization of the generated scenarios including application of different renovation approaches sounds crucial. For the development of an efficient DSS to this end, the decision architecture should be designed systematically. This can be addressed through use of *computational design synthesis field* principles. The field of computational design synthesis has been an active area of research for almost half a century [6] in other domains such as Mechanical Design. Research advances in this field have increased the sophistication and complexity of the designs that can be synthesized, and advances in the speed and power of computers have increased the efficiency with which those designs can be generated [6]. Oberhauser et al. [7] state that by use computational design synthesis a constrained solution space can be automatically generated and a high number of design candidates can be quickly explored without fixation on common designs. In this regard, the authors in [6] discuss that computational design synthesis methods in general need to integrate four main activities: Representation of the attributes of the design space (design alternatives, objectives and constraints are specified); Generation, which uses this representation to propose candidate solutions; Evaluation with regard to final objectives; and feedback from the evaluation called Guidance, which is used to steer the search process in subsequent iterations. In this classification, the representation of the attributes of the design space is considered the most essential step, which is a question of modelling of *systems architecture*. Jankovic et al. [8] argue the systems architecting process consists of modelling of requirements and constraints, generation of possible architectures and their evaluation with regard to desired performances. Ulrich [9] defines system architecture as "(1) the arrangement of functional elements; (2) the mapping from functional elements to physical components; (3) the specification of the interfaces among interacting physical components". For Crawley [10], the system architecture is "the embodiment of concept and the allocation of physical/informational function to elements of form, and definition of interfaces among elements and with the surrounding context". Eppinger et al. [11] define system architecture as "the structure of the system, embodied in its elements, their relationships to each other (and to the system's environment), and the principles guiding its design and evolution – that give rise to its functions and behaviours". Relying on these descriptions, Hamida et al. [12] state that the functional architecture represents one facet of the system architecture and links system design intentions to the physical world. For developing a system architecture, Bonjour et al. [13] argue that matrix-based product modelling methods represent the product architecture, product elements and their relationships, shown as a matrix. They are being increasingly used by Sharman et al. [14], since they can support different research goals, for example, product modularization [13], analysis of technical interactions either within the products or within the project organization [15], design analysis [16], and change propagation analysis.

Bonjour et al. [13] discuss that system architecture modelling relies on different kinds of matrix in order to design a complex system in a systematic and coherent way. The authors [13] based on Malmqvist [17] distinguished two levels of product analysis that are related to different design goals. First, product-level matrices, which provide a mapping between a set of properties or other elements and a number of "whole" alternatives. The motivation for such methods is to support decision-making about the entire product life cycle or about product platforms of which product-level variants are the "parts." Developing product platforms requires considerations of common and unique modules within a brand and within a platform but also requires seeing each product variant as a whole [18,19]. Second, element-level matrices represent the relationships between the elements/parts/components of a single product in a matrix. According to Bonjour et al. [13], there are two subtypes of element-level matrices, including:

- Interdomain Matrix or Incidence Matrices (IMs) or Domain Mapping Matrices (DMMs) represent relationships between two domains. They can represent a set of design decisions or relationships between what and how;
- Intradomain Matrix or Dependency Structure Matrix (DSM). Intradomain matrices represent relationships between elements of the same domain, for example, between components.

Danilovic et al. [20] state that DMM analysis augments traditional DSM analyses. They [20] sum up that comparison of DSM and DMM approaches reveal that DMM analysis offers several benefits. For example, it can help (1) capture the dynamics of PD (product development), (2) show traceability of constraints across domains, (3) provide transparency between domains, (4) synchronize decisions across domains, (5) cross-verify domain models, (6) integrate a domain with the rest of a project or program, and (7) improve decision making among engineers and managers by providing a basis for communication and learning across domains. To say briefly, the DSM and DMM approaches are complementary to each other with the difference that DSM focuses on one domain while DMM focuses on the interaction between domains. Furthermore, according to Danilovic et al. [21] the DSMs and DMMs can be combined to provide engineers a situational visibility, in which individuals can understand the need for information exchange, interdependencies and the context of the project. This will lead to transparency within and between domains in a project, between a project and the basic organization, and between projects. This reduces the risk and uncertainty, as individuals understand the whole situation and have a better insight in their responsibility. It is also possible for such matrices to perform analyses such as clustering. As an example DMM can aid in visualizing dependencies between teams within one project towards other projects i.e., how other projects affect or relate to teams that are carried out in the project of interest. Clusters in the matrix can identify the level of interdependencies between teams and the other projects [22].

1.2. Matrix-based approaches for building renovation context

According to Alexander [23], Pimmler [24] and Alfaris et al. [25], the general approach when developing complex systems is to decompose the product into subsystems, and, if the subsystems are still too complex, decompose these into smaller components. Using matrix-based methods, further, can also represent relationships and couplings between or within them. In the following development of this article, we consider that system architecture for generation of the renovation scenarios is composed of modules and integrative elements that fulfil system functions. Therefore, the system architecture is defined by focusing on interactions throughout enabling a matrix methodology to include not just one domain at a time but to allow for the mapping between two domains. The two domains are 'sustainability objectives/criteria' and 'renovation approaches'. This is carried out by developing a DMM based on empirical studies. As such, the DMM that is developed in this paper, demonstrates how renovation approaches can be mapped to the sustainability objectives/criteria and vice versa.

Development of the DMM for building renovation entails three steps including (1) identification of the sustainability objectives/criteria, (2) discovering and structuring the renovation approaches, (3) and finally investigation of the dependencies among its elements. It provides the primary elements for systems architecture of a DSS that can be used to develop holistic scenarios for refurbishment actions. It further aims to enhance the required insight and addresses the issues for developing the DSS. Moreover, by following [20], developing such a matrix for building renovation similarly can (1) capture the dynamics between the renovation approaches and the sustainability objectives/criteria, (2) show traceability of constraints across objectives/criteria, (3) provide transparency between the mentioned elements, (4) synchronize decisions across the domains, (5) cross-verify domain models, (6) integrate an objective/criteria with the rest of the project, and (7) improve decision making among design team, engineers, and other key stakeholders who are involved in the renovation process by providing a basis for communication and learning across domains. It therefore plays a strong roll to deal with existing complexity regarding to the large number of renovation alternatives and various types of criteria. Above all, it can be used to consider the propagation of the values, as well as tracking of other values (or added value) regarding to the other considered criteria (i.e. spatial quality) while the focus is on optimization/enhancement of some common criteria i.e., improvement of energy efficiency or reduction of the investment cost.

2. Application and development of a DSS (Decision Support Systems) for building renovation

Developing systems architecture for a DSS for generation of sustainable building renovation scenarios is an intricate, challenging task. The increasing complexity of decision problems regarding to the fulfilment of sustainability objectives/criteria, the growing number of subjects involved and keen competition between conflicting costs and interests make decisions and decision support difficult. In order to involve all the sources which can add value in renovation projects, the authors [26] explored the decision-making processes for building renovation, through introducing three different decision-making levels. The levels help stakeholders in the renovation process to discuss their project "on the same level" and make transparent decisions in a rational order. In that study [26], two typical decision-making frameworks were developed. Subsequently, the decision-making on third level of the second framework including use of Multi Objective Decision Making – MODM [27] was considered as the integrated design process implementation and evaluation for sustainable renovation and entitled *scientific decision-making*. Following this concept, Kamari et al. [28,29] proposed a HMSR (Holistic Multi-methodology for Sustainable Renovation) which aims to deal with the complexity and "soft" nature of the retrofitting problem involving different decision makers with different priorities. As the result of this effort, a multi-methodology based on mixing certain Soft Systems Methodologies (SSM) with Multiple Criteria Decision Making (MCDM) methods including 23 steps was developed. There is a strong reasoning for development and application of a DSS [30,31,5] in the body of the HMSR for generation of the renovation scenarios.

There are a remarkable number of early stage DSS for sustainable building renovation [32]. They are used by owners and designers mostly to plan energy efficiency retrofitting. Nielsen et al. [32] stated that almost 30% of the DSS (10 out of 43 studied tools) have been developed to generate the design alternatives. Ferreira et al. [33,34] concluded that these DSS (which are capable of making design alternatives) are mostly focus on technical performance enhancement of renovation approaches and therefore used by engineers. This means the DSS have just been begotten to deal with certain Hard (or quantifiable) engineering criteria such as energy efficiency, investment costs etc. and this leads to generate sub-optimal solutions. While as mentioned in section 1, the existing building stock should benefit from more holistic renovation approaches embarking on sustainability objectives in its full sense. In this perspective, an optimal renovation scenario is achieved higher scores depends on the selected criteria from intervention of both Soft (i.e. spatial quality) and Hard (i.e. energy efficiency) criteria. Consequently for development of a DSS to generate holistic renovation scenarios, the question arises in regard to the holistic sustainability objectives (see section 2.1), possible renovation alternatives (see section 2.2). Development of a DMM (see section 2.3), further, indicates how these two interact on each other (see section 3). This consideration, therefore, deepen the knowledge about what value is, how value is created, and where the value will be added in building renovation context.

2.1. Sustainability Objectives/Criteria

There are a wide array of advantages that can be obtained as an outcome of a holistic and sustainable retrofitting to higher energy performance standards. Many are tangible and possible to quantify, while others are less so and may be difficult to allocate a monetary value. These renovation goals must be identified and targeted early in the design process while renovation scenarios are developed. Regarding the full scope of this discussion, Kamari et al. [35] addressed a new "Holistic sustainability decision-making support framework for building renovation" by applying Checkland's Soft Systems Methodologies – SSM [36] beside Keeney's Value Focused Thinking – VFT [37]. As such, sustainability was defined and represented in its full sense from three categories including Functionality, Accountability and Feasibility (18 sustainable value oriented criteria [118 sub-criteria] have been identified) for holistic/deep building renovation purpose (see Fig. 1).

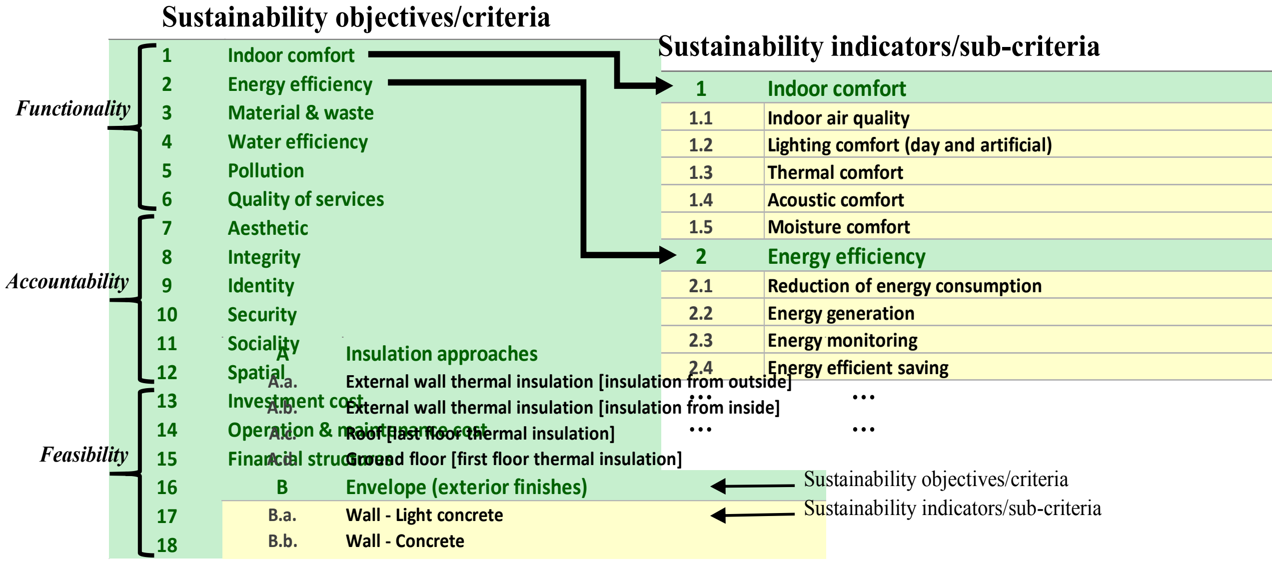

Fig. 1. Sustainability objectives/criteria for building renovation

2.2. Renovation Approaches

There are a broad range of renovation approaches that can be applied for the renovation of existing buildings including insulation approaches, replacement of existing windows, integration or replacement of existing equipment, heating/cooling system, building envelope implementation of roof and partially of facades to avoid thermal bridges, total building envelope implementation, volumetric additions, partial replacement of existing windows, partial building envelope implementation, integration of PV and solar collectors on the roof/facades etc. [38]. For the development of a database of renovation approaches, the relevant data have been collected from literature [38,39,40], evaluation of the 10 European renovation research projects [41], as well as investigation of the SIGMA database by Molio [42]. Moreover, a renovated building project (the Section 3 of Skovgårdsparken located in 8220 Brabrand, Denmark) has been studied. It was a Residential building (including nine blocks), Modernistic in terms of typology, built during 1968/72. It has been renovated by Brabrand Housing Association. The case has been selected due to a comprehensive renovation scenario (i.e. insulation of walls, renovation of foundation, installation of PV etc.) that has been applied for the renovation purpose. The results in total led to expand a list of 26 renovation categories including 139 renovation alternatives (see Fig. 2). It should be noted, however, that they are not necessarily separate components; indeed, integration of actions in any renovation project is very important.

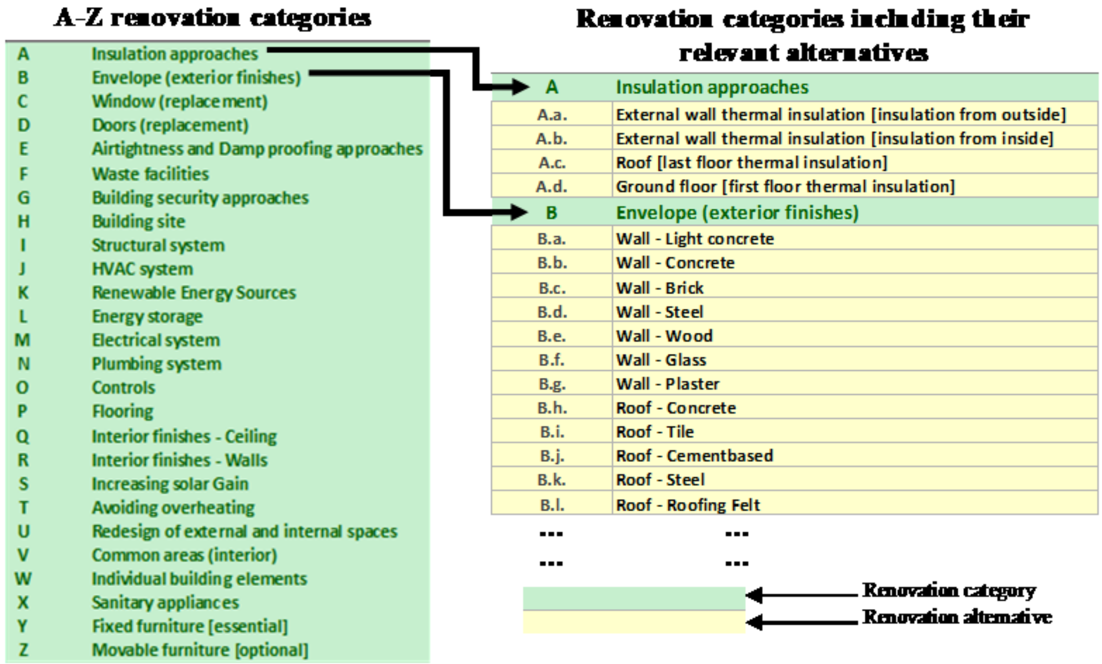

Fig. 2. Structure of the A-Z renovation categories and their relevant alternatives

2.3. Domain Mapping Matrix (DMM) for building renovation

The DMM developed in this paper represents the components in building renovation and their interactions, thereby highlighting the system's architecture (or designed structure). The matrix representation of the DMM is a rectangular and binary (i.e. a matrix populated with only zeros and ones) with m rows and n columns, whereas m is the number of renovation alternatives and n is the number of sustainability sub-criteria (see Fig. 3). If there exists a dependency from node i to node j (equivalent to $a_{i,j}$), then the value of the item $a_{i,j}$ (column i, row j) is unity (or flagged with a mark such as "X"). Otherwise, the value of the element is zero (or left empty).

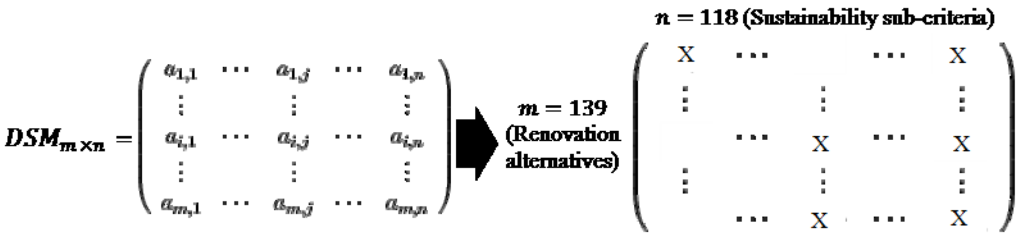

Fig. 3. The DMM for building renovation with m number of renovation alternatives and n number of sustainability sub-criteria (the mark "X" has been used if there exists a dependency between elements node i to node j)

3. Findings

Developing the DMM in this study indicated the presence or absence of a relationship between pairs of renovation alternatives and sustainability sub-criteria for renovation projects. Having an overview of the number of dependencies from the sustainability criteria (and sub-criteria) into the renovation alternatives (see Fig. 4) indicates that

- the criteria 'indoor comfort', 'quality of the services', 'energy efficiency' from *Functionality category*; 'investment cost', 'financial structures', 'flexibility & management' from *Feasibility category*; and 'aesthetic', 'security and safety', 'spatial quality' from *Accountability category* are respectively more affected criteria comparing to the others in their own category.
- the *criteria* 'investment cost', 'financial structures', 'flexibility & management', 'aesthetics', 'indoor comfort', and 'energy efficiency' are respectively the most impressive/affected ones resulted from application of the renovation alternatives. That means in a typical renovation process these criteria have to be targeted and prioritized in early design stages. It is due to the large number of connections between them and the other criteria. Obviously, they make more values as well.
- the *sub-criteria* 'procurement', 'affordability of residential rental', 'commissioning', 'energy consumption', 'durability and reliability', and 'degree to which the colors harmonize' are respectively the most connected to the renovation alternatives. It demonstrates their importance and ability to gain more scores in a holistic renovation process. In another perspective, this also point out different ways of generating these values/objectives by use of various renovation approaches.

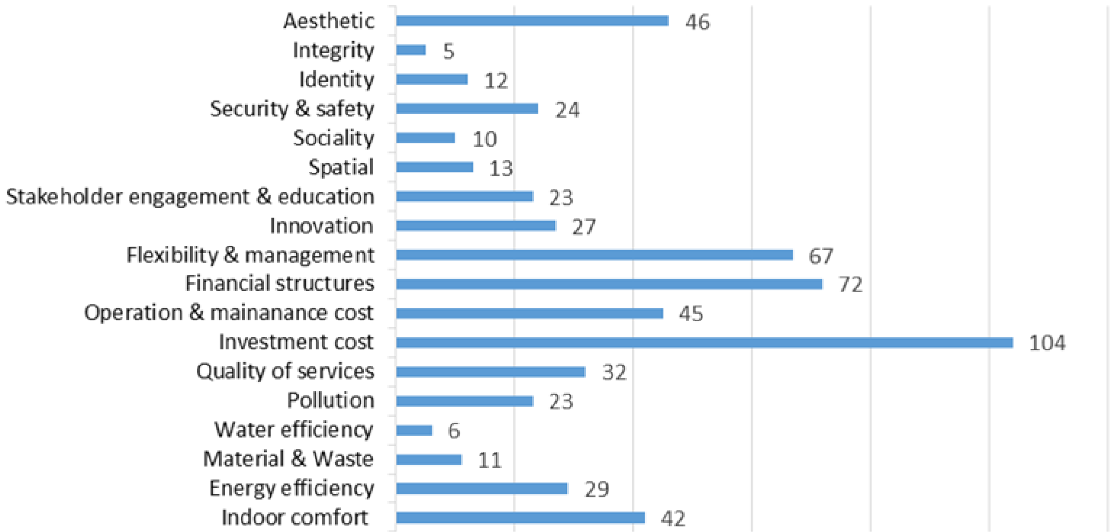

Fig. 4. The average number of dependencies for renovation sustainability criteria, from the sub-criteria (total 118) into the renovation alternatives (total 139)

Having an overview of the number of dependencies from the renovation alternatives into the sustainability criteria (see Fig. 5) indicates that

- application of the *renovation solution categories* 'windows (replacement)', 'avoiding overheating', 'envelope (exterior finishes)', 'insulation approaches', and 'waste facilities' are respectively influencing more sub-criteria. The results suggest how the values (objectives/criteria) are affected comprehensively by use of different renovation strategies. It enables us to track where the value will be created and where the value will be added. For instance, the analysis shows that use of the category 'windows (replacement)' has an average of 38 dependencies with various sub-criteria. That means replacement of the windows as part of the renovation strategy influences sub-criteria under 'indoor comfort', 'energy efficiency', 'material & waste', 'pollution', 'quality of services', 'all related costs', 'aesthetic', 'security & safety', 'sociality' etc. due to existing dependencies among them.
- application of the *renovation alternatives* 'reducing external heat gains [use of sun-shading]', 'external insulation', 'window replacements', 'renewable energy technologies', 'wall - exterior finishes', 'roof – exterior finishes', 'indoor climate control', 'fire places', 'structural system', and 'HVAC system' respectively embark on more sub-criteria and therefore they create more values in renovation process. Next, the values (objectives/criteria) that have been created should be investigated and demonstrated to all stakeholders in the process.

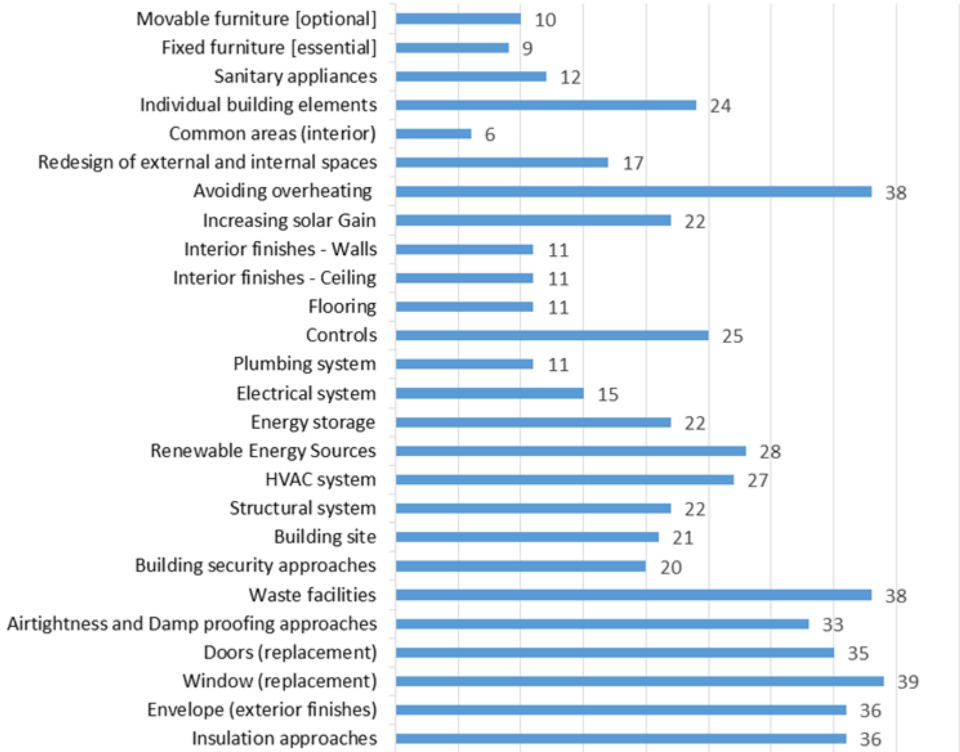

Fig. 5. The average number of dependencies for renovation categories, from the renovation alternatives (total 139) into the sustainability sub-criteria (total 118)

4. Discussion

In previous section, the functional characteristics (renovation objectives/criteria) have been propagated to the physical components (renovation approaches) through development of a DMM to help the system architects to be aware of the effects of the decisions they make in the early design process. The DMM provided a simple, compact and visual representation of the system (here refers to renovation context) in the form of a matrix. In addition, it described the implication of Active (Hard or technical) renovation approaches (i.e. replacement of the windows) beside Passive (Soft or architectural) renovation approaches (i.e. redesign of internal or external spaces). The evidence of a holistic renovation influence of an energy renovation (use of pure technically designed renovation scenarios) is that many of the measures taken in energy renovation, which affect architectural quality and social aspects, are not necessarily related to energy concerns (or pure technically designed renovation scenarios). In other words, implementation of energy renovation scenarios also affects 'integrity', 'sociality', 'aesthetic', and 'spatial' quality in buildings and its impacts should not be overlooked. The exploration of this concept is a way to create and to track the added values related to other criteria in this field. For example by tracking the renovation alternative "indoor climate control", it is realized that it influences "indoor comfort", "energy efficiency", "quality of services", "investment cost" criteria, and at the same time, it adds value to all the sub-criteria under "Stakeholder engagement and education". Surprisingly, the Active renovation approaches influence the Soft criteria and vice versa, remarkably. As well, many of the results were expected such as the cost criteria including 'investment cost', 'operation and maintenance cost', and 'financial structures' should be considered and prioritized as the most effective criteria, and therefore most crucial to cope with in selection of the renovation alternatives. Moreover, the renovation may bring changes in the built area, which these changes affect, most of other Soft criteria in nature. Another expected result was the impact of 'stakeholder engagement and education' criteria and sub-criteria in connection to renovation approaches such as 'energy consumption', 'waste facilities', 'controls', '’increasing solar gains', and 'redesign of external and internal spaces'. Also the criteria 'flexibility and management' was expected to link to high number of dependencies.

As Danilovic et al. [22] argued, the DMM-analysis can perform or deal with transformation of information between domains, traceability of information between domains and system elements, synchronization of information and activities between domains, verification of system models and project assumptions, integration of the individual systems into a cohesive project/program system and improved quality of decision making. Particularly, for development of a DSS that described in section 2, a DMM advantages include compact format, visual nature, intuitive representation, powerful analytical capacity, and flexibility in the system. Moreover, the DMM can be applied on one hand, as a hierarchical decomposition that includes multilevel abstraction and design parameter identification, and on the other hand, a multi-domain formulation, which includes parameter dependency identification, design cycle identification and decision structuring, and scoping. These all are crucial and vital for development of a DSS which is able to produce appropriate renovation scenarios. It should be noted that there exists more and more facts, which can be discussed and hence resulted from consideration of the DMM in this paper. That means the outcomes for use and advantages of use of such a matrix in order to model the system architecture for building renovation can certainly be expanded further.

5. Conclusion and Further studies

5.1. Conclusion

Designing a large-scale complex system, such as development of holistic renovation scenarios, with a focus on sustainability requires a systematic approach toward integrated design of all subsystems (here is referred to the objectives/criteria). Domains such as sociality, identity, spatial quality, energy, and water are all coupled. Designing each one in isolation can lead to sub-optimality where sustainability is achieved in one aspect but at the expense of other aspects. This study investigated the development of a DSS for generation of renovation scenarios with the aims to represent and navigate across existing dependencies between its elements. As such, the renovation sustainability objectives/criteria and the renovation approaches were discovered, explored and structured through development of a DMM. DMM is used for modeling and analyzing system architecture of complex product development processes. A major advantage of the DMM that was developed in this study was in its compactness and ability to provide a systematic mapping among its elements (represented in rows and columns) that was clear and easy to read regardless of size. It helped to cope with the existing complexity among its elements due to the broad number of approaches and the various objectives/criteria, which need to be embarked on in a holistic renovation. Consequently, it can be used to demonstrate what the values are (sustainability objectives/criteria), how they can be created (application of renovation approaches), and where the value can be added by generation of the integrated renovation scenarios (use of the DMM). Moreover, using the DMM in the body of a DSS for generation of renovation scenarios can help to reduce the number of traditional design iterations as well as to find out about the holistic perspectives of the value and tracking of the added value. In another perspective, it can help to optimize the flow of "data" through the system and identify coupled elements within the system. Optimization of these two objectives can provide a great deal of insight into how a DSS should be structures.

5.2. Further studies

A complete modeling system, which can detect any system in its complexity, is called multiple-domain matrix. This combines different DSMs and DMMs into one comprehensive model, which also allows analyzes across multiple domains and different types of relations. For this purpose, in the future, the aggregated DSMs can be determined and used as specific views into the DMM. Application of DSMs and DMMs to different systems allows a much more targeted handling of complex systems. The matrices therefore should be developed by interviewing system architects with fixing rules. It concerns calibration of the dependencies between the elements in the DMM in order to be used as the main body of a holistic DSS for generation of most efficient and appropriate renovation scenarios.

Acknowledgements

The authors of the paper would like to show their gratitude to the Danish Innovation Foundation for financial support through the RE-VALUE research project.

References

[1] Jensen PA, Maslesa E. Value based building renovation – A tool for decision making and evaluation. *Building and Environment* 2015; **92**:1-9.

[2] Galiotto N, Heiselberg P, Knudstrup M. Integrated Renovation Process: Overcoming Barriers to Sustainable Renovation. *Journal of Architectural Engineering* 2015; **22**.
[3] SBi - Ministry of Climate, Energy and Building - Danish government. Strategy for energy renovation of building: The route to energy-efficient buildings in tomorrow's Denmark; 2014, Retrieved from http://www.kebmin.dk/
[4] BPIE - Buildings Performance Institute Europe. Europe's buildings under the microscope; 2011, Retrieved from http://bpie.eu/wp-content/uploads
[5] Juan Y, Gaob P, Wangc J. A hybrid decision support system for sustainable office building renovation and energy performance improvement. *Energy and Buildings* 2010; **42**(3):290–297.
[6] Cagan J, Campbell MI, Finger S, Tomiyama T. A Framework for Computational Design Synthesis: Model and Applications. *Journal of Computing and Information Science in Engineering* 2005; **5**(3):171-181.
[7] Oberhauser M, Sartorius S, Gmeiner T, Shea K. Computational Design Synthesis of Aircraft Configurations with Shape Grammars. In Gero J, Hanna S, editors. *Design Computing and Cognition* '14. Cham: Springer; 2015.
[8] Jankovic M, Eckert C. Architecture decisions in different product classes for complex products. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 2016; **30**:217–234.
[9] Ulrich K. The role of product architecture in the manufacturing firm. *Research Policy* 1995; **24**:419–440.
[10] Crawley E. Introduction to System Architecture - Architecture to Value; 2007, Retrieved from http://ocw.mit.edu/courses/engineering-systemsdivision/esd-34-system-architecture-january-iap-2007/lecture-notes/lec1.pdf.
[11] Eppinger SD, Browning TR. *Design Structure Matrix Methods and Applications*. Cambridge: MIT Press; 2012.
[12] Hamida SB, Grandou A, Jankovic M, Eckert C, Huet A, Bocquet J. A Comparative Case Study of Functional Models to Support System Architecture Design. *Procedia Computer Science* 2015; **44**:325–335.
[13] Bonjour E, Deniaud S, Dulmet M, Harmel GA. Fuzzy Method for Propagating Functional Architecture Constraints to Physical Architecture. *Journal of Mechanical Design* 2009; **131**(6).
[14] Sharman D, Yassine A. Characterizing Complex Product Architectures. *Journal of Systems Engineering* 2004; **7**(1):35–60.
[15] Szykman S, Racz J, Bochenek C, Sriram RD. A web-based system for design artifact modeling. *Design Studies* 2000; **1**:145–165.
[16] Suh NP. *Principles of Design*. Cambridge: Oxford University Press; 1990.
[17] Malmqvist J. A Classification of Matrix-Based Methods for Product Modeling. In :Marjanovic D, editor, *Proceedings of the 7th International Design Conference 2002 (DESIGN02), Cavtat-Dubrovnik*. Cavtat-Dubrovnik, Croatia: Design Society; 2002.
[18] Dahmus JB, Gonzalez-Zugasti JP, Otto KN. Modular Product Architecture. *Design Studies* 2001; **22**(5):409-424.
[19] Jiao J, Simpson T, Siddique Z. Product Family Design and Platform-based Product Development: a State-of-the art Review. *Journal of Intelligent Manufacturing* 2007, **18**(1):5-29.
[20] Danilovic M, Browning TR. Managing complex product development projects with design structure matrices and domain mapping matrices. *International Journal of Project Management* 2007; **25**:300–314.
[21] Danilovic M, Sandkull B. The use of dependence structure matrix and domain mapping matrix in managing uncertainty in multiple project situations. *International Journal of Project Management* 2005; **23**:193–203.
[22] Danilovic M, Browning T. A formal approach for domain mapping matrices (DMM) to complement design structuring matrices (DSM). In: *proceedings of the 6th international design structure matrix (DSM) workshop*, Cambridge, UK; 2004.
[23] Alexander C. *Notes on the Synthesis of Form*. Cambridge: Harvard University Press; 1964.
[24] Pimmler TU, Eppinger SD. Integration Analysis of Product Decompositions. In: *Process ASME Design Theory and Methodology Conference (DTM'94)*; 1994, p. 343-351.
[25] Alfaris A, Siddiqi A, Rizk C, de Weck O, Svetinovic D. Hierarchical Decomposition and Multidomain Formulation for the Design of Complex Sustainable Systems. *Journal of Mechanical Design* 2010; **132**(9).
[26] Kamari A, Corrao R, Petersen S, Kirkegaard PH. Sustainable Renovation Framework: Introducing three levels of Integrated Design Process Implementation and Evaluation. In: *PLEA 2017 conference*, Edinburgh, UK; 2017, p. 781-788. Retrieved from http://nceub.org.uk/PLEA2017/proceedings/PLEA2017_proceedings_volume_I.pdf
[27] Climaco J. *Multicriteria analysis*. New York: Springer; 1997.

[28] Kamari A, Jensen SR, Corrao R, Kirkegaard PH. Towards a holistic methodology in sustainable retrofitting: Theory, Implementation and Applications. In: *WSBE 2017 (World Sustainable Built Environment) conference*, Hong Kong, China; 2017, p. 702-708. Retrieved from http://www.wsbe17hongkong.hk/download/WSBE17%20Hong%20Kong%20-%20Conference%20Proceedings.pdf

[29] Kamari A, Jensen SR, Corrao R, Kirkegaard PH. A Holistic Multi-methodology for Sustainable Renovation. *International Journal of Strategic Property Management* 2017; Manuscript has been submitted for publication.

[30] Näegeli C, Ostermeyer Y, Kharseh M, Kurkowska I, Wallbaum H. A Multidimensional Optimization Approach to Refurbishment Design on a Multi-Building Scale. *In WSBE 2017 (World Sustainable Built Environment) conference*, Hong Kong, China; 2017, p. 709-715. Retrieved from http://www.wsbe17hongkong.hk/download/WSBE17%20Hong%20Kong%20-%20Conference%20Proceedings.pdf

[31] Yin H, Stack P, Menzel K. Decision Support Model For Building Renovation Strategies. *World Academy of Science, Engineering and Technology, Computing in Civil Engineering* 2011; **76**:834-841.

[32] Nielsen AN, Jensen RL, Larsen TS, Nissen SB. Early stage decision support for sustainable building renovation: A review. *Building and Environment* 2016; **103**:165–181.

[33] Ferreira J, Pinheiro MD, Brito JD. Refurbishment decision support tools: A review from a Portuguese user's perspective. *Construction and Building Materials* 2013a; **49**:425–447.

[34] Ferreira J, Pinheiro MD, Brito JD. Refurbishment decision support tools review—Energy and lifecycle as key aspects to sustainable refurbishment projects. *Energy Policy* 2013; **62**:1453–1460.

[35] Kamari A, Corrao R, Kirkegaard PH. Sustainability focused Decision-making in Building Renovation. *International Journal of Sustainable Built Environment* 2017; Manuscript has been accepted ahead of publication. doi:10.1016/j.ijsbe.2017.05.001

[36] Checkland P. Soft systems methodology: a thirty year retrospective. *Systems Research and Behavioral Science* 2000; **17**:11–58.

[37] Keeney RL. *Value-Focused Thinking*. Cambridge: Harvard University Press; 1992.

[38] Boeri A, Antonin E, Gaspari J, Longo D. *Energy Design Strategies for Retrofitting: Methodology, Technologies, Renovation Options and Applications*. Southampton: WIT Press; 2014.

[39] Baker N. *The Handbook of Sustainable Refurbishment: Nondomestic Buildings*. London: Earthscan; 2009.

[40] Burton S. *The Handbook of Sustainable Refurbishment: Housing*. Abingdon: Earthscan; 2012.

[41] Kamari A, Corrao R, Petersen S, Kirkegaard PH. Tectonic Sustainable Building Design for the development of renovation scenarios – Analysis of ten European renovation research projects. In: *SER4SE 2018 (seismic and Energy Renovation for Sustainable Cities) conference*, Catania, Italy; 2017, Manuscript has been submitted for publication.

[42] Molio. Molio Price data; 2016, Retrieved from https://molio.dk/molio-prisdata/prisdata-footer/brug-molio-prisdata/

SER 4SC

9 788896 386569

~~euro 10,00~~ copia omaggio