SBE16 Sydney: International High-Performance Built Environments Conference

- CONFERENCE PROGRAM -

17th - 18th November, 2016

Australian National Maritime Museum - 2 Murray St, Sydney, NSW, 2000

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Thursday, 17th November

08.30 **Registration**

Tasman Light Gallery

08.45 - 09.00 **Welcome**

Lighthouse Gallery

- Dr Lan Ding and A/Professor Francesco Fiorito - Co-Chairs of SBE16 Sydney

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09.00 - 09.15 **Opening Address**

Chair: Professor Helen Lochhead

Lighthouse Gallery

- Professor Lucy Turnbull AO - Chief of the Greater Sydney Commission and Adjunct Professor in UNSW Built Environment

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09.15 - 10.45 **Plenary Session 1**

Chair: Dr Lan Ding and A/Professor Francesco Fiorito

Lighthouse Gallery

- Professor Helen Lochhead, Dean of UNSW Faculty of Built Environment
  Resilience by Design: Can an Innovative Process Deliver More?

- Scientia Professor Deo Prasad AO, CEO of CRC for Low Carbon Living
  Lowering the Carbon Footprint of Buildings and Cities

- Nils Larsson, Representative of the SBE Series Partners, CIB, iiSBE ,UNEP-SBCI, FIDIC and Global ABC
  The COP Series of Meetings, the Global Alliance for Building and Construction and Related Activities

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10.45 - 11.15 **Morning Coffee Break - *Terrace Room***

11.15 - 13.00

Performance Assessment in Built Environments, Session 1

Lighthouse Gallery

Chair: Lester Partridge (LEHR)
Vice-chair (rapporteur): Emanuele Naboni (Royal Danish Academy of Fine Arts)

- **Michael Ambrose** - Air tightness of new Australian residential buildings (31864)
- **Sumin Kim** - Green features, symbolic values and rental premium: systematic review and meta-analysis (32933)
- **Lester Partridge** - The latest demonstrated technical innovations in Sydney CBD tall building: Case study (33151)
- **Enas Alkhateeb** - Potential of upgrading federal buildings in the United Arab Emirates to reduce energy demand (33444)
- **Ayokunle Olubunmi Olanipekun** - Motivation and owner commitment for improving the delivery performance of green building projects: A research framework (33452)
- **Zubair Syed** - Performance of earthquake-resistant RCC frame structures under blast explosions (33548)
- **Huibo Qian** - Effect of insulation ground on anti-condensation in rural residence (33596)
- **Mohamed Khallaf** - Performance-based design of tall building envelopes using competing wind load and wind flow criteria (33624)
- **Emanuele Naboni** - Thermal comfort-CFD maps for architectural interior design (33856)

Design Innovation and Collaboration, Session 1

The Theatre

Chair: Alistair Sproul (UNSW)
Vice-chair (rapporteur): Anir Kumar Upadhyay (UNSW)

- **Mohammed Mehdi Azizi** - The effects of urban block forms on the patterns of wind and natural ventilation (32053)
- **Xiaolong Zhao** - Research on Optimization and Biological Characteristics of Harbin Trees Based on Thermal Comfort in Summer (32086)
- **Janet Victoria Stia** - Bioclimatic design approach in Dayak traditional longhouse (33260)
- **Cristian Lavin** - Optimization of an external perforated screen for improved daylighting and thermal performance of an office space (33476)
- **Samin Marzban** - An evolutionary approach to single-sided ventilated façade design (33635)
- **Mitra Panahian** - Assessing potential for reduction in carbon emissions in a multi-unit of residential development in Sydney (33639)
- **Alemu Tiruneh Alemu** - Airflow and temperature modelling of sustainable buildings at the design stage can prevent unintended consequences of passive features (33647)
- **Mahsan Sadeghi** - Optimization of wind tower cooling performance; a wind tunnel study of indoor air movement and thermal comfort (33653)
- **Cong Wang** - Multi-objective optimization and parametric analysis of energy system designs for the Albano university campus in Stockholm (33684)
- **Saeed Banihashemia** - Modular coordination-based generative algorithm to optimize construction waste (40312)

Smart Built Environments, Session 1

Waterside Studio

Chair: Philip Oldfield (UNSW)
Vice-chair (rapporteur): Sara Shirowzhan (UNSW)

- **Carlos Bartesaghi Koc** - A methodological framework to assess the thermal performance of green infrastructure through airborne remote sensing (32027)
- **Mat Santamouris** - The concept of smart and NZEB buildings and the integrated design approach (32043)
- **Jonathan Fox** - The effect of building facades on outdoor microclimate – dependence model development using terrestrial thermography and multivariate analysis (32787)
- **Mat Santamouris** - Aerial survey and in-situ measurements of materials and vegetation in the urban fabric (33527)
- **Venugopalan S. G. Raghavan** - Determination of optimal parameters for wind driven rain CFD simulation for building design in the tropics (33687)
- **Mahboobeh Karima (TBC)** - Interactive building environments: A case study university building in UAE (33958)
- **Hawra Askari (TBC)** - Smart vs. sustainable: A case study government building in Dubai, UAE (34011)
- **Md Asrul Nasid Masrom** - A preliminary exploration of the barriers of sustainable refurbishment for commercial building projects in Malaysia (37971)
- **Balaji Mohan** - Development of chemical reaction kinetics of VOC ozonation (38181)
- **Yingyi Zhang** - Using parametric modelling in form-based code (FBC) design for high-dense cities (32584)

13.00 - 14.00

Lunch - *Terrace Room*

Poster Exhibition - *Tasman Light Gallery*

14.00 - 15.00

Plenary Session 2

Chair: Professor Bruce Judd

Lighthouse Gallery

- Mr Man-Kit Leung, Director of Hong Kong Green Building Council
  Design for Energy Efficient High-Rise Residential Buildings in Warm-Humid Climate
- Professor Mat Santamouris, Anita Lawrence Chair in High Performance Architecture, UNSW
  Cooling of Buildings - Past Present Future

15.00 - 15.30

Afternoon Tea Break - *Terrace Room*

15.30 - 17.30

Performance Assessment in Built Environments, Session 2 - *Integrated Sustainability Assessment*

Lighthouse Gallery

Chair: Thomas Wiedmann (UNSW)
Vice-chair (rapporteur): Robert Crawford (University of Melbourne)

- **Monique Fouche** - Towards an integrated approach for evaluating both the life cycle environmental and financial performance of a building: A review (33236)
- **Toktam Bashirzadeh Tabrizi** - The impact of different insulation options on the life cycle energy demands of a hypothetical residential building (33326)
- **Jianqiang Yang** - Integrated sustainability assessment and renewal of old industrial areas: A case study on Changzhou (33573)
- **Parisa Pakzad** - Developing key sustainability indicators for assessing green infrastructure performance (33583)
- **Robert H Crawford** - Towards an automated approach for compiling hybrid life cycle inventories (33611)
- **Maryam Khoshbakht** - Cost-benefit prediction of green buildings: SWOT analysis of research methods and recent applications (33621)
- **Soo Huey Teh** - Replacement scenarios for construction materials based on economy-wide hybrid LCA (33630)
- **Julie R Jupp** - 4D BIM for environmental planning and management (33648)
- **Fatima Afzal** - An investigation of corporate approaches to sustainability in the construction industry (33910)
- **Man Yu** - The carbon footprint of Australia's construction sector (34621)

Sustainability Policy and Governance

The Theatre

Chair: Kevin Yee (NSW Department of Planning & Environment)
Vice-chair (rapporteur): Edgar Liu (UNSW)

- **Wei Xiao** - Fully exploring traditional Chinese culture and promoting organic development of green city (32203)
- **Edgar Liu** - Carbon reduction programs and lower income households in Australian cities (32733)
- **Sumin Kim** - Tenants' decision to or not ro lease green & non-green buildings: A conceptual framework (32853)
- **Melissa James** - Retrofit or behaviour change? Which has the biggest impact on energy consumption in low income households? (32943)
- **Larissa Strömberg** - Verified climate declarations for evaluation of contractors' design (33327)
- **Abbas Elmualim** - CSR and sustainability in FM: Evolving practices and integrating index (33415)
- **Kai Chen Goh** - Barriers and drivers of Malaysian BIPV application: Perspective of developers (33457)
- **Pao-Hsiung Chiu** - CFD methodology development for Singapore green mark building application (33636)
- **Shaila Divakarla** - Supply Chain Risk to Reward: Responsible Procurement and the Role of Ecolabels (33826)
- **Wiktoria Glad** - Everyday governance of domestic energy systems (33892)
- **AbdulLateef Olanrewaju** - Analysis of Homeowners' Behaviours in Housing Maintenance (37206)

Industry, Government and University Collaboration - *Education for Sustainable Built Environments*

Waterside Studio

Chair: Mark Smith (Transport for NSW)
Vice-chair (rapporteur): Jules Moloney (Deakin University)

- **Jun Ma** - Mapping for the future: Business intelligence tool to map regional housing stock (31905)
- **Tayyab Ahmad** - The effects of high-rise residential construction on sustainability of housing systems (32582)
- **Mark C Smith** - Industry, government & academia – A relationship paradigm fit for the future of transport infrastructure assets (33279)
- **Cielo Roldan** - Greening rail infrastructure for carbon benefits (33280)
- **Mike Burbridge** - If living labs are the answer – what's the question? A review of the literature (33460)
- **Usha Iyer-Raniga** - Challenges in aligning the architecture profession in Indonesia for climate change and sustainability (33592)
- **Jules Moloney** - Serious games for integral sustainable design: level 1 (33662)
- **Parinee Srisuwan** - Field investigation on indoor thermal environment of a high-rise condominium in hot-humid climate of Bangkok, Thailand (33675)
- **Margaret M Gollagher, Jenny Campbell** - Collaboration achieves effective waste management design at Brookfield Place Perth, Western Australia. (33817)
- **Tomi Winfree** - Learning for low carbon living: The potential of mobile learning applications for built environment trades and professionals in Australia (37191)

18.30 - 19.00

Dinner Canapé

19.00 - 22.00

Conference Dinner

Novotel Sydney on Darling Harbour
100 Murray St, Pyrmont NSW 2009

Friday, 18th November

08.30 - 09.30 **Plenary Session 3** *Chair: Professor Alan Peters*

Lighthouse Gallery

- Professor Peter Newton, Swinburne University, Fellow of the Academy of Social Sciences in Australia
  Innovation for a Sustainable Low Carbon Built Environment Transition

- Professor Dennis Else, Executive Director of Multiplex
  Carbon Value Engineering - Making VE a Noble Pursuit!

09.30 - 11.00

Performance Assessment in Built Environments, Session 3

Lighthouse Gallery

Chair: Paul Bannister (Innovation & Sustainability at Energy Action)
Vice-chair (rapporteur): Sara Wilkinson (UTS)

- **Tamaraukuro Amasuomo** - Development of a Building Performance Assessment and Design Tool for Residential Buildings in Nigeria. (32048)
- **Sara Wilkinson** - Evaluating the thermal performance of retrofitted lightweight green roofs and walls in Sydney and Rio de Janeiro. (32176)
- **Pattaranan Takkanon** - UHI and Thermal Performance of Office Buildings in Bangkok (33576)
- **Yen-Yi Li** - The Study on the Evaluation of Thermal Insulation Efficiency with Typical Plant Species of Roof Greenery in Kaohsiung (32606)
- **Paul Bannister** - Load resilience in high performance buildings (33622)
- **David M Whaley** - Cost benefit analysis of simulated thermal energy improvements made to existing older South Australian houses (33659)
- **Haiqiang Liu** - Evaluation on the energy consumption and thermal performance in different residential building types during mid-season in hot summer and cold-winter zone in China (33685)
- **Alistair B Sproul** - Admittance/Fourier series revisited: understanding periodic heat flows (33739)

Design Innovation and Collaboration, Session 2

The Theatre

Chair: Michael Ambrose (CSIRO)
Vice-chair (rapporteur): Melissa James (CSIRO)

- **Nigel Howard** - Environmental Assessment & Rating – Have we Lost the Plot? (31451)
- **Aaron Davis** - Co-creating urban environments to engage citizens in a low-carbon future (33307)
- **William Craft** - Development of a regenerative design model for building retrofits (33551)
- **Jiandong Ran** - Effect of building roof insulation measures on indoor cooling and energy saving in rural areas in areasin Chongqing (33589)
- **Malay Dave** - Performance and perception in prefab housing: An exploratory industry survey on sustainability and affordability (33618)
- **Ke Xiong** - Energy-saving renovation of Bayu traditional residence—Taking Anju Town of Chongqing as the example (33668)
- **Shabnam Yazdani Mehr** - Adding more by using less: Adaptive reuse of woolstores (38940)
- **Armando Coppola** - Nanomaterials and smart nanodevices for modular dry constructions: the project "Easy House" (41489)

Built Environment Resilience, Session 1

Waterside Studio

Chair: Chris Derksema (City of Sydney)
Vice-chair (rapporteur): Samantha J Hall (UNSW)

- **Chris Derksema** (Invited talk)
- **Adriana Sanchez** - Are some forms of resilience more sustainable than others? (31315)
- **S.M. Karim** - Co-benefits of low carbon policies in the built environment: An investigation into the adoption of co-benefits by Australian local government (31999)
- **Cristopher Kim** - The effect of social capital on co-production: towards community-oriented development in post-disaster recovery (33623)
- **Samantha J Hall** - Evidence based practice for the built environment: Can systematic reviews close the research - practice gap? (33672)
- **Keiko Hirota** - A Study of Urban Green Park for Low-carbon Built Environmental Design and Satoyama Ecosystem Management (33711)

Smart Built Environments, Session 2

Yots Café

Chair: Julie Jupp (UTS)
Vice-chair (rapporteur): Thomas M. Lawrence (University of Georgia)

- **Mat Santamouris** - Development of net zero energy settlements using advanced energy technologies (31900)
- **Thomas M. Lawrence** - Data flow requirements for integrating smart buildings and a smart grid through model predictive control (32051)
- **AHM Mehbub Anwar** - Examining the effects of transport policy on modal shift from private car to public bus (32111)
- **Sarbeswar Praharaj** - Innovative civic engagement and digital urban infrastructure: Lessons from 100 Smart Cities Mission in India (32758)
- **Nobuyuki Sunaga** - Solar town Fuchu- plan and performance (32916)
- **Elias Naber** - From the building level energy performance assessment to the national level: How are uncertainties handled in building stock models (33554)
- **Sara Shirowzhan** - Building classification from Lidar data for spatio-temporal assessment of 3D urban developments (33878)
- **Shinji Yamamura** - Assessment of urban energy performance through integration of BIM and GIS for smart city planning (33886)

11.00 - 11.30 — **Morning Coffee Break - *Terrace Room***

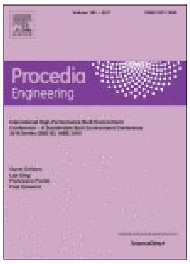
11.30 - 13.00

Performance Assessment in Built Environments, Session 4 — *Lighthouse Gallery*	Design Innovation and Collaboration, Session 3 — *The Theatre*	Built Environment Resilience, Session 2 — *Waterside Studio*	High Performance Materials and Emerging Technologies, Session 1 — *Yots Café*
Chair: Brian Ashe (Australian Government Department of Industry, Innovation & Science) *Vice-chair (rapporteur): Dennis Lee (NSW Office of Environment & Heritage)*	*Chair: Steve Burroughs (SBE Australian Board Member)* *Vice-chair (rapporteur): Daniel Sang-Hoon Lee (Royal Danish Academy of Fine Arts)*	*Chair: Paul Osmond (UNSW)* *Vice-chair (rapporteur): Indrika Rajapaksha (University of Moratuwa)*	*Chair: Gabriele Masera (Polytechnic University of Milan)* *Vice-chair (rapporteur): Ingrid Paoletti (Polytechnic University of Milan)*
• **Caroline Residovic** - The new NABERS indoor environment tool - The next frontier for Australian buildings (32208) • **Dennis Lee** - Life cycle cost comparison of high NABERS performing commercial buildings (32340) • **Brian Ashe** - Enabling innovation in building sustainablility: Australia's national costruction code (32931) • **Anir Kumar Upadhyay** - Post-occupancy energy consumption of BASIX affected dwellings in the Sydney metropolitan area (33281) • **Marini Samaratunga** - Modelling and analysis of post occupancy behaviour in residential buildings to inform BASIX sustainability assessments in NSW (33422) • **Krishna Munsami** - The role of post occupation evaluation in achieving high performance buildings through diagnostics (33590) • **Jin Woo** - A post-occupancy evaluation of a modular multi-residential development in Melbourne, Australia (33651) • **Federico Tartarini** - Indoor environment and perceptions of occupants in nursing homes: a field study (33663)	• **Timothy Greenaway** - Assessment of potential energy and greenhouse gas savings in the commercial building sector by using solar energy for air-conditioning purposes (32334) • **Eunike Kristi Julistiono** - Structural pattern's granularity variation to optimize a vertical structure (32812) • **Yu Liu** - A preliminary study on the climate adaptive design of green rural houses in west China (32928) • **Daniel Sang-Hoon Lee** - Exploring the relationship between structurally defined geometrical parameters of reinforced concrete beams and the thermal comfort on indoor environment (33145) • **Sepani Senaratne** - Recycled concrete in structural applications for sustainable construction practices in Australia (33221) • **Emanuele Naboni** - The use of facade mockups in in LCA based architectural design (33859) • **Manish Kewalramani** - Engineered cementitious composites for modern civil engineering structures in hot arid coastal climatic conditions (38865)	• **Mat Santamouris** - Thermal comfort conditions at the platforms of the Athens Metro (31962) • **Paul Osmond** - A suitable thermal stress index for the elderly in summer tropical climates (32239) • **Ehsan Sharifi** - Heat resilience in public space and its applications in healthy and low carbon cities (33423) • **Ehsan Sharifi** - Spatial and activity preferences during heat stress conditions in Adelaide: towards increased adaptation capacity of the built environment (33432) • **Porntip Ruengtam** - Factor analysis of built environment design and management of residential communities for enhancing the wellbeing of elderly people (33495) • **Indrika Rajapaksha** - Effect of spatial ambience on thermal adaptation in tropics: Case of free running shared spaces in coastal hotels of Sri Lanka (33743) • **Rubing Han** - Study passive evaporative cooling technique on the water-retaining roof brick (33848) • **Sayanthan Ramakrishnan** - A comparative study on the effectiveness of passive and free cooling application methods of phase change materials for energy efficient retrofitting in residential buildings (33914)	• **Sara Wilkinson** - Exploring the feasibility of algae building technology in NSW (32077) • **John Dadzie** - Relationship between sustainable technology and building age: evidence from Australia (32155) • **Gabriele Masera** - Development of a super-insulating, aerogel-based textile wallpaper for the indoor energy retrofit of existing residential buildings (33344) • **Ingrid Paoletti** - Mass customization with additive manufacturing: New perspectives for multi performative building component in architecture (33430) • **Gabriele Masera** - Prefabrication as large-scale efficient strategy for the energy retrofit of the housing stock: an Italian case study (33632) • **Sayanthan Mr Ramakrishnan** - Thermal energy storage enhancement of lightweight cement mortars with the application of phase change materials (33755) • **Eleftheria Touloupaki** - Energy performance optimization as a generative design tool for nearly zero energy buildings (35480) • **Jitka Hroudova** - The possibilities of modification of crop-based insulation materials applicable in civil engineering in low-energy and passive houses (35836)

13.00 - 14.00 — **Lunch - *Terrace Room***

Poster Exhibition - *Tasman Light Gallery*

Time	Performance Assessment in Built Environments, Session 5 *Lighthouse Gallery*	Design Innovation and Collaboration, Session 4 *The Theatre*	Built Environment Resilience, Session 3 *Waterside Studio*	High Performance Materials and Emerging Technologies, Session 2 *Yots Café*
14.00 - 15.30	*Chair: Brett Pollard (HASSELL)* *Vice-chair (rapporteur): Marina Neophytou (University of Cyprus)* • **Wei Xiao** - Green Darning City, Taking the tenth China (Wuhan) international garden EXPO Design as examples (32200) • **Claudio Aurelio Diaz** - Influence of rainfall on the thermal and energy performance of a low rise building in diverse locations of the hot humid tropics (33566) • **Jane Loveday** - A technique for quantifying the reduction of solar radiation due to cloud and tree cover (33570) • **Margaret Kam** - Towards zero carbon in a hot and humid subtropical climate (33726) • **Yupeng Wang** - Simulation study of urban residential development and urban climate change in Xi'an, China (33912) • **Marina Neophytou** - "How can a multi-scale analysis guide smart urban energy demand management? An example from London City Westminster Borough" (34297) • **Marina Neophytou** - The pollutant removal capacity of an urban street canyon and its link to the breathability and exchange velocity (34298)	*Chair: Jim Plume (UNSW)* *Vice-chair (rapporteur): David Marchant (Woods Bagot)* • **David Marchant** - Including stakeholder intent in precinct information models (32557) • **Tayyab Ahmad** - BIM-based iterative tool for sustainable building design: a conceptual framework (32598) • **W.K. Chow (TBC)** - An expert system for firefighting guidelines in supertall buildings (32600) • **Grit Ngowtanasuwan** - Casual Model of BIM Adoption in Thai Architectural and Engineering Design Industry (33494) • **James Redwood** - The proliferation of ICT and digital technologies systems and their influence on the dynamic capabilities of construction firms (33456) • **Giuseppina Uva** - Modelling framework for sustainable co-management of multipurpose exhibition systems: the "Fiera del Levante" case (33916) • **Jim Plume** - Proposal for an open data model schema for precinct-scale information management (37977)	*Chair: Fabio Fatiguso (Polytechnic University of Bari)* *Vice-chair (rapporteur): Mark Dewsbury (University of Tasmania)* • **Mat Santamouris** - Transformation through renovation: An energy efficient retrofit of an apartment building in Athens (31985) • **Siti Akhtar Mahayuddi** - Assessment of building typology and construction method of traditional longhouse (33346) • **Fabio Fatiguso** - Resilience of historic built environments: inherent qualities and potential strategies (33496) • **Steve Burroughs** - Development of a tool for assessing commercial building resilience (33677) • **Jason E Bretherton** - Christchurch's high performance rebuild (33688) • **Gabriele Masera** - Identification of technological and installation-related parameters for a multi-criteria approach to building retrofit (33689) • **Mark Dewsbury** - Temperate climates, warmer houses and built fabric challenges (33872)	*Chair: Gianluca Ranzi (University of Sydney)* *Vice-chair (rapporteur): Samad Sepasgozar (UNSW)* • **Yunpeng Wu** - Effect of thermal conductivity of lightweight cement composite on heat transfer through panels exposed to a sun simulator (33419) • **Rudy Djamaluddin** - Relationship model of the moment capacity of GFRP sheet strengthened RC beams to the duration of sea water exposure (33540) • **Nagaraj HB** - Compressed Stabilized Earth Blocks Using Iron Mine Spoil Waste - An Explorative Study (33578) • **Jacques Remy Minane** - Upgraded mineral sand fraction from municipal solid waste incineration (MSWI) bottom ash: an alternative solution for the substitution of natural aggregates in concrete applications (33693) • **Khalegh Barati** - Optimal driving pattern of on-road construction equipment for emissions reduction (33722) • **Karel Dvořák** - The improvement of the pozzolanic properties of recycled glass during the production of blended Portland cements (35834) • **Samad Sepasgozar** - A scanner technology acceptance model for construction projects (36616)
15.30 - 16.30	**Closing Ceremony and Best Paper Awards - *Lighthouse Gallery***			
16.30 - 17.00	**Drinks and Afternoon Tea - *Terrace Room***			



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International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

Editorial

Lan Ding[a], Francesco Fiorito[a], Paul Osmond[a]

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Peer-review under responsibility of the organizing committee iHBE 2016

Keywords: design innovation; resilience; sustainability performance assessment; materials; smart built environments; policy

1. Introduction

This Procedia Engineering issue contains 182 papers accepted by the SBE16: International High-Performance Built Environment Conference (iHBE 2016) held on 17 and 18 November in Sydney, Australia. Jointly organised by UNSW Built Environment and CRC for Low Carbon Living, the conference is part of the Sustainable Built Environment (SBE) 2016 Series and aims to drive research innovation in design, planning and management of high-performance built environments, as well as promoting education and collaboration in this field.

The conference covered a wide range of themes including:

- Performance Assessment in Built Environments
- Design Innovation and Collaboration
- Built Environment Resilience
- High-Performance Materials and Emerging Technology
- Smart Built Environments
- Sustainability Policy and Governance
- Education for Sustainable Built Environments
- Industry, Government and University Collaboration

Fig 1 includes an overview of the distribution of papers among the conference themes.

Peer-review under responsibility of the organizing committee iHBE 2016
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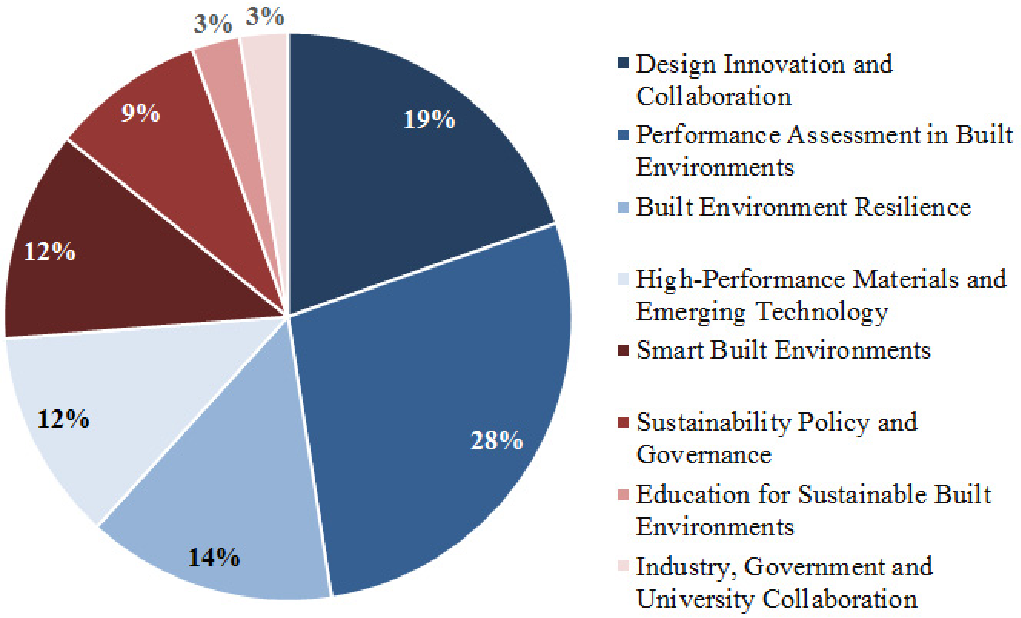

Fig. 1. Overview of the distribution of papers within the conference themes.

2. Overview of Conference Sessions

An opening address by Professor Lucy Turnbull AO, Chair of the Greater Sydney Commission and Adjunct UNSW Professor set the scene for a lively and productive conference.

The initial plenary session was led by UNSW Built Environment Dean Professor Helen Lochhead, CEO of the CRC for Low Carbon Living Scientia Professor Deo Prasad AO, and Nils Larsson, Executive Director of the international SBE conference series. Subsequent plenary speakers were Mr Man-Kit Leung from the Hong Kong Green Building Council; UNSW's Anita Lawrence Chair Professor Mat Santamouris, who explored the past, present and future of building cooling; Professor Peter Newton (Swinburne University) who spoke on innovation for a sustainable low carbon built environment transition; and Professor Dennis Else, Executive Director of Multiplex, who addressed the intriguing topic of reducing carbon emissions through value engineering.

Day one highlights – from different ends of the built environment spectrum – included a presentation on automating the compilation of life cycle inventories [1] and a talk on whether retrofit or behaviour change has the bigger impact on energy consumption in low income households [2]. Day two continued this broad range of topics to exercise delegate's minds. For example, how Australia's National Construction Code could be harnessed to support innovation in building sustainability [3]; a new, probabilistic approach to life cycle cost analysis [4]; and innovations in concrete recycling [5].

This breadth of topics was reinforced in the top student presentations, which included topics on the energy efficiency potential of wind towers [6]; a study of occupant perceptions of nursing home indoor environments [7]; a research on the spatial and activity preferences of Adelaide residents during heatwaves [8]; an introduction to a BIM-based iterative tool for sustainable building design [9]; and substitution of bottom ash from waste incineration in concrete applications [10].

3. Conference Committees

We would like to express our sincerest thanks to SBE16 Sydney Organising Committee, International Advisory Committee, International Scientific Committee, Postgraduate Committee, Keynote Speakers and all authors of the papers.

Organising Committee:
Lan Ding, UNSW, Australia (Conference Co-Chair)
Francesco Fiorito, UNSW, Australia (Conference Co-Chair)
Alan Peters, UNSW, Australia
Deo Prasad, UNSW, Australia
Mat Santamouris, UNSW, Australia
Benson Lim, UNSW, Australia
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Maria Kolokotroni, Brunel University London, UK
Roberto Lamberts, Federal University of Santa Catarina, Brazil
Nils Larsson, Representative of the SBE Series Partners, CIB, iiSBE, UNEP-SBCI, FIDIC & Global ABC
Jiang Wu, Tongji University, China
Fengting Li, Tongji University, China
Saffa Riffat, University of Nottingham, UK
Frank Schultmann, Karlsruhe Institute of Technology, Germany
Nasir Shafiq, University Technology PETRONAS, Malaysia
Anjali Krishan Sharma, Amity University, India

International Scientific Committee:
Francesco Fiorito, UNSW, Australia (Co-Chair)
Paul Osmond, UNSW, Australia (Co-Chair)
Philip Oldfield, UNSW, Australia (Co-Chair)
Bassam Abdel-Karim Abu-Hijleh, British University in Dubai (BUiD), UAE
Yong Han Ahn, Western Carolina University, USA
Michael Ambrose, CSIRO, Australia
Paul Bannister, Energy Action, Australia
Seifu Bekele, Global Wind Technology Services Pty. Ltd, Australia
Umberto Berardi, Ryerson University, Canada
Steve Burroughs, SBE Australian Board Member, Australia
Raymond Cole, University of British Columbia, Canada
Robert Crawford, University of Melbourne, Australia
Enrico De Angelis, Polytechnic University of Milan, Italy
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4. The SBE16 Series and SBE16 Sydney

The SBE16: International High-Performance Built Environment Conference in Sydney is part of the Sustainable Built Environment (SBE) Conference 2016 Series. The SBE conference series has grown into an important and significant global event with the aim to share research innovation and to provide excellent opportunities for international collaboration.

The SBE conference series are operated by the following organisations:

- CIB: International Council for Research and Innovation in Building and Construction
- iiSBE: International Initiative for a Sustainable Built Environment
- UNEP-SBCI: United Nations Environment Programme, Sustainable Buildings and Climate Initiative
- FIDIC: International Federation of Consulting Engineer
- Global ABC: Global Alliance for Buildings and Construction

The SBE16 Sydney conference was sponsored by UrbanGrowth NSW that is a government agency which focuses on urban transformation projects, delivering vibrant and connected urban spaces for the public.

The SBE series is held on a three-year cycle, culminating in a global conference in year 3. The present cycle concludes with the World Sustainable Built Environment Conference 2017 Hong Kong (WSBE17 Hong Kong), from 5 to 7 June 2017.

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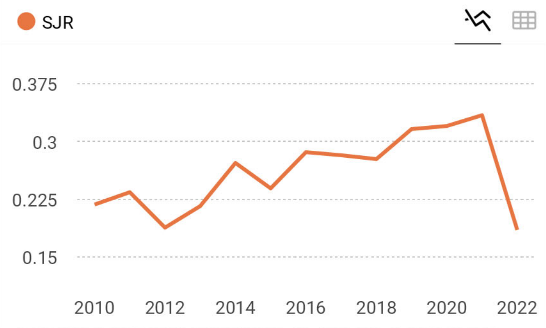

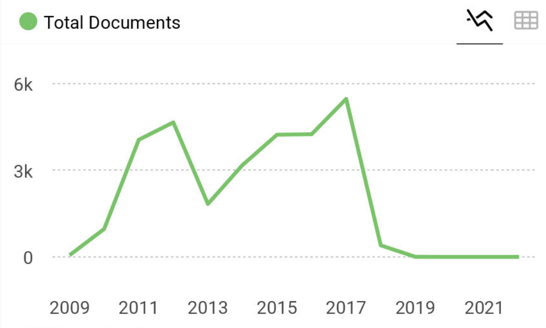

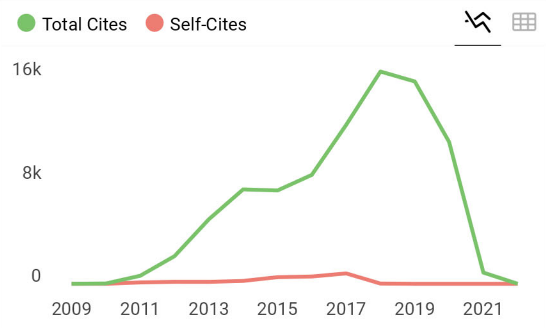

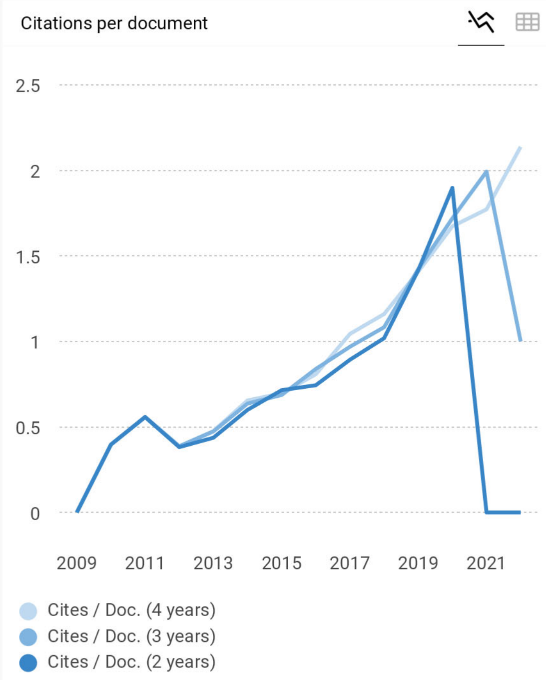

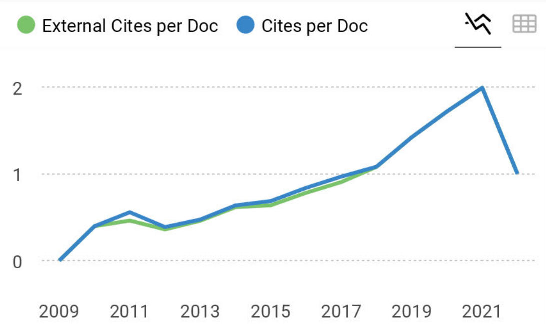

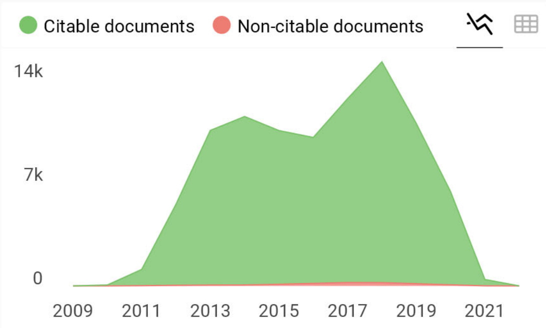

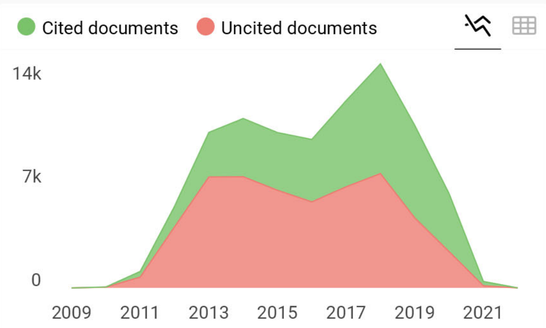

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Structural pattern's granularity variation to optimize a vertical structure

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Abstract

The increasing demand of vertical buildings has encouraged the development of vertical structure optimization. Most optimization has focused on size optimization. However, shape/form optimization and pattern/topology optimization are believed to have more impact not only towards structural efficiency, but also to the aesthetic of the building. Modifying structural pattern on the vertical building's perimeter has great potential to improve the structural performance, not only to satisfy the efficiency criteria, but also to fulfil functional and aesthetic consideration. Thus, previous research has been performed to optimize the performance of the vertical structure by applying different patterns of the perimeter structure. Result showed that among three non-routine patterns applied and orthogonal pattern as the benchmark, triangular pattern is the optimum in terms of efficiency, economy, expressiveness, and environmental sustainability. This paper examines the effect of granularity variation of triangular pattern employed on the perimeter of vertical buildings to optimize the structural performance. In here, granularity of the pattern is taken as the key structural feature to be manipulated in increasing further the efficiency of the structure. Medium and high-rise buildings are taken as the case studies to examine the performance of each pattern under two loading conditions - vertical and horizontal loads. For each case, triangular pattern in three different degrees of granularity are modelled using CAD modelling and optimized with structural design and optimization software. Results from different granularities applied are then compared, and analyzed to decide the effect of the structural pattern's granularity variation towards the efficiency of the structure.

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Keywords: Triangular pattern; granularity; structural optimization; efficiency

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1. Introduction

Nowadays, there is an increasing demand of vertical building structures, especially in big cities and the central business districts. The reasons are the increasing number of population due to globalization or migration from sub-urban to urban area and land scarcity in urban area. Other reason is the concept of sustainable living in a mixed-used building. Driven by the awareness to minimize resources and energy for sustainable development, vertical mixed-used building where people can live, work, eat, and even have entertainment all in a single building is considered beneficial to achieve efficiency in energy and resources, especially in reducing the transportation energy [1].

Demand of vertical buildings has been followed by development of vertical structure optimization. Considering that buildings are responsible for around 40% of the world's energy, and even 50-80% in metropolitan areas, it is essential to aim on an efficient building structure [2]. In fact, more than four decades of research to optimize vertical structures has resulted a broad range of computational optimization methods, which are shape/form optimization, pattern/topology optimization and size optimization. Most research has focused on size optimization which is an effort to achieve structural efficiency by optimizing the size/dimension of structural components. In here, geometry and topology of the structure are unchanged in the optimization process, and therefore the dimension of structural components is the only key feature to be optimized. However, realizing that geometry and topology of the structure are actually more potential to increase the structural efficiency, some research has focused on modifying the structural form and pattern. The structural form is the 2D or 3D geometry of the structure, while the structural pattern is the topology or connectivity and arrangement of structural members.

Modifying the structural pattern of a vertical building to optimize its structural efficiency has several benefit. Variation of structural pattern on the perimeter of vertical buildings has given certain aesthetics towards a ubiquitous and monotone prismatic form, especially considering that limitation of site and functional consideration usually does not allow much modification of the vertical building's form. This becomes the reason for the emerging of prismatic vertical building with distinct perimeter patterns, such as COR Building in Miami [3] and Hearst Tower in New York [4].

Various structural patterns used in the vertical buildings has driven a question regarding which pattern is the optimum pattern for medium and high-rise buildings. Thus, previous research has been performed to find the optimum pattern for the vertical buildings [5]. In that research, orthogonal pattern has been compared with three non-routine patterns - triangular, hexagonal, and diamond; as the structural pattern employed on perimeter of vertical buildings. For two different loading conditions - vertical loads for medium-rise case and lateral loads for high-rise case; each pattern is applied on the perimeter of a prismatic structure. Then, the results are compared in terms of efficiency, economy, expressiveness, and environmental sustainability (4Es). The research concludes that triangular pattern is the optimum pattern for resisting both vertical and horizontal loads.

Conclusion of the previous research [5] supports the recent development of diagrid structural system [4]. Over the last 10 years, more vertical buildings (from medium-rise height to the tall and even super tall structures) have used diagrid system as their structural system, due to the structural efficiency and the versatility of diagrid [6]. This fact has proven that triangular pattern is the optimum pattern for vertical buildings. Some research has observed different geometries of diagrid resulted from different modules of diagrid and angles of diagonal members [7]. However, some questions remain and can be investigated further, such as the effect of the changes on pattern granularity towards the structural performance. Does denser granularity give more structural efficiency? Considering bigger size of triangles results less stiffness and then requires bigger size of the members.

This paper examines the influence of changing the structural pattern's granularity towards the efficiency of the structure. Since this research is the continuation of the previous research, thus the triangular pattern as the optimum pattern decided in the previous research [5] is taken as the pattern to be observed. For two cases observed - the medium and high-rise structures; triangular pattern in three distinct granularities are applied on the perimeter of the structures. Then, the optimized structures resulted are compared in term of their structural efficiency, to examine the influence of changing the pattern granularity towards the structural performance, and decide the optimum granularity.

2. Structural pattern optimization

2.1. Structural pattern

Structural pattern can be defined as a certain arrangement of structural components which has impact on the appearance of the structure as well as structural behavior and construction complexity. Structural components here can be columns and beams, or structural members in trusses or skeleton structure, or bearing walls/shear walls in wall structure. Structural pattern can be seen on the building elevation directing the arrangement of columns and beams or other structural members, on a building plan showing the arrangement of columns or other vertical members, or on three-dimensional image of the surface structure [5].

Structural pattern optimization is a structural optimization process aiming in increasing the structural performance of a building by optimizing its structural pattern. Effort to modify structural patterns in order to increase the structural performance has been found throughout development of structural system. However, recently there has been more application of various structural patterns in vertical structures, due to the prospect of structural patterns to increase the structural performance and driven by the development of computer technology.

There are three objects of optimization in the development of structural optimization; form/geometry, topology, and size/dimension. Structural pattern is a structural feature which includes information regarding all three. A structural pattern has geometry description, granularity and connectivity of the components, and also dimensions of the members, to be considered in its modification. Therefore, in investigating the structural pattern, there is a need to take into account the influence of structural pattern's geometry and granularity.

2.2. Similar research

There are only few research trying to optimize structural pattern on the perimeter of the vertical buildings. Most optimization related to the vertical building structure with diagonal bracing still focuses on size optimization [8]. A method to design and optimize the pattern of diagonal bracings in vertical buildings utilizing an evolutionary process has been introduced by researchers from George Mason University in Investor 2001 software [9]. In this program, a stable structure with a certain arrangement of diagonal bracings is taken as an input, and then it is optimized through an evolutionary process until an efficient pattern is resulted.

Besides, optimization of diagonal bracings in high-rise structures has also been carried out using modified pattern search which did not only focus on size optimization, but also tried to find an efficient pattern of diagonal bracings through an evolutionary process by eliminating non beneficial bracing members [10]. Pattern gradation of braced frame structure has also been performed using topology optimization [11].

In above research, structural pattern optimization is automatically performed by utilizing computer as a design partner, executed using structural analysis and optimization software whether through an evolutionary process or a random search. In this research, the optimization process focuses on the granularity modification of initial structural pattern. However, considering a limited resource (structural optimization software which is still based on size optimization), varying the structural pattern's granularity is carried out manually through CAD modelling.

2.3. Previous research

Previous research has been performed with the objective to find the optimum structural pattern for the perimeter of vertical buildings, compared to the routine orthogonal pattern [5]. Research was started by looking for the possible non-routine patterns from natural structures and recent building structures. Three non-routine patterns - triangular, diamond, and hexagonal, were chosen, modelled and optimized. Then, the optimized structures produced from the three patterns were then compared, and the optimum solution was decided in terms of efficiency, economy, expressiveness, and environmental sustainability (4Es). Result showed that triangular pattern is the optimum pattern for both medium and high-rise cases.

Founding of the previous research that triangular pattern is the optimum pattern has confirmed the efficiency of diagrid structure. Diagrid is a perimeter structure with triangular pattern which is vastly used in various scale of vertical buildings. It is very adaptable in structuring any structural building forms and spans [4]. Diagrid system is known for its structural efficiency. Compared to conventional exterior braced frame structures, diagrid eliminates all vertical columns, since the diagonal members can also carry the gravity loads. Compared to conventional tubular structure with rigid frame, diagrid is more efficient since it works with axial forces, and thus minimizing the shear deformation of the framed tube system [7].

Looking at applications of diagrid structure, there are various sizes of triangular pattern employed on the buildings. Some use small modules of diagrid, such as Capital Gate in Abu Dhabi [4], while others use medium and large modules of diagrid, such as Hearst Tower in New York [4] and The Bow Tower in Calgary [12]. Different size of triangular patterns produces different granularity of structural pattern used. Thus, this paper tries to examine which granularity is more optimal for improving the structural performance.

3. Structural optimization problems and methodology

3.1. Design requirements

As in the previous research [5], two cases are observed in this research - medium and high-rise case, to examine structural efficiency towards vertical loads and lateral loads respectively:

- Medium-rise case observed has a building height of 80m (20 stories high), with a slenderness ratio of 2:1
- High-rise case has a building height of 240m (60 stories high), with a slenderness ratio of 6:1

The above ratio is determined based on the definition and ratio of medium and high-rise structures [13].

Three behavioral requirements - stability, stiffness, and strength, are considered to obtained a feasible design solution. Here, the usual limits on stresses and deflections are applied as constraints. The vertical deflection is limited to less than (span/250) mm and the lateral sway is limited under (height/300) mm [13].

Two design loads are considered during the research, for medium and high-rise cases respectively. To simplify the process, the same design loads (based on Australian Standard) used in previous research [5] is applied:

- The vertical imposed loads recommended in AS1170.1:2002, which is a uniform distributed load of 3kPa for office building, is used in medium-rise case.
- Whereas for high-rise case, the wind pressures on windward wall are calculated based on AS1170.2:2002, with assumption that the site is located in Sydney urban terrain with no shielding from the surroundings. Thus, the wind loads applied in the structures are varied from 0.432kPa on the ground, increasing to 1.037kPa on the peak of the building (240m high above ground).

3.2. Structural features

Prismatic form with square plan is chosen as the form of the structure to be observed, with the plan dimensions of 40m x 40m. 4m is set as the floor-to-floor height to produce the desired building height and slenderness ratio, as mentioned in Section 3.1. Since the pattern to be applied in the perimeter structure observed is triangular pattern, thus some adjustments of building corners are allowed, such as indentation and inclined faces.

For both medium and high-rise cases, three different granularities of triangular pattern are applied to the perimeter structure and compared. In here, the triangular pattern from previous research [5] is taken as the benchmark, and then scaled into 50% and 25%.

- Alternative 1 (the benchmark) uses triangular pattern with 4-story triangles, similar to the pattern used by The Hearst Tower in New York [4].
- Alternative 2 uses triangular pattern with 2-story triangles, as the pattern used by Swiss Re Tower in London [4] and Tornado Tower in Doha [14].
- Alternative 3 uses triangular pattern with 1-story triangles, as the pattern used by Mode Gakuen Cocoon Tower in Tokyo [15] and Capital Gate in Abu Dhabi [4].

The three granularities observed can be seen in Fig. 1. All three patterns use the same geometry of triangular pattern with a diagrid angle of 67º, which considered as an optimal range of diagrid angle for tall buildings [7].

In computer modelling, structural analysis and optimization, all joints are set to be rigid, and all supports are set to be fixed. The perimeter structure is the only structural element modelled and analyzed, with assumption that perimeter structure and a 16m wide central core are two sub-systems which work together in resisting both vertical and lateral loads [16]. Assuming that the central core resists 50% of the vertical loads and 40% of the lateral loads, the loads used in modelling, analysis and optimization of the perimeter structure alternatives can be reduced. Floor beams at each story are not included in the model, except if the floor beams are parts of the triangular pattern observed. However, the stiffness of the diagonal members due to the bracing of the floor beams is taken into consideration.

The structural material used in the research is grade 350 steel to minimize the size of the members. Circular Hollow Section steel library is used in discrete size optimization.

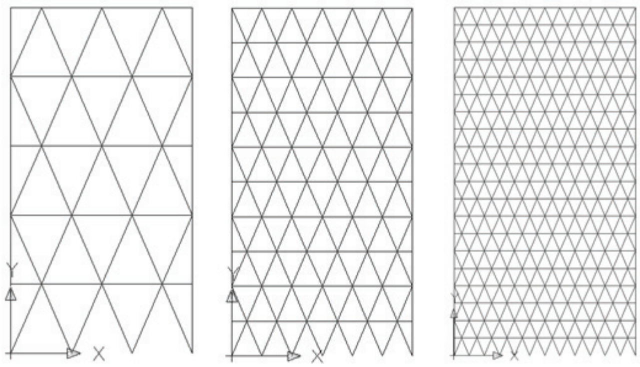

Fig. 1. Three different granularities of triangular pattern compared in the research.

3.3. Decision criteria

In previous research [5], two types of criteria were used in finding the optimum structural pattern for vertical building. The first one is efficiency criterion, while the second is multi-criteria of efficiency, economy, expressiveness, and environmental sustainability (4Es). The limitation of using multi-criteria is the fact that most structural optimization software/tool still operates based on single criterion of efficiency. Thus, other criteria should be defined manually.

Since the purpose of this research is to examine the effect of variation on structural pattern's granularity towards the performance of vertical structure, efficiency is chosen as the main decision criterion to be considered, both for medium and high-rise cases. The reason behind is because in this research, optimization process is carried out using Multiframe4D which works with single criterion of efficiency. Besides, since the geometry of the pattern is fixed, which is triangular pattern, aesthetic/expressiveness of the alternatives are considered to be quite similar. Whereas, the indicator of environmental sustainability criterion is also efficiency, showing minimum amount of resource usage. Meanwhile, the economy criterion is still considered by grouping of structural members, but it is not a decisive factor.

Structural efficiency indicates the percentage of the strength of the material in each structural component uses to resist structural loads. Efficiency is the ratio of the load carried by a structure to its total weight (strength to weight ratio). An efficient structure is a structure which has maximum strength with minimum weight [17]. Therefore, using efficiency as decision criteria, means alternatives observed are compared in term of the material weight used to withstand the same loads. In this research, the indicator of efficiency is the total mass of each structure resulted through optimization process. Thus, in evaluating structural performance of patterns with different granularities, the total mass of each design using certain granularity becomes the indicator to be compared.

3.4. Research methodology

To examine distinct pattern granularities, triangular pattern used in the previous research [5] is used as the benchmark, and then compared to the same triangular pattern with different degree of granularities. For each granularity observed, 3D model of the perimeter structure is created using CAD modelling. After that, the 3D wireframe model is imported into Multiframe4D software, to be assembled into a complete structure. Then, the initial structure is analyzed and optimized with discrete size optimization, until the most efficient structure is obtained.

Two computational processes are involved in this research, as shown in Fig. 2.

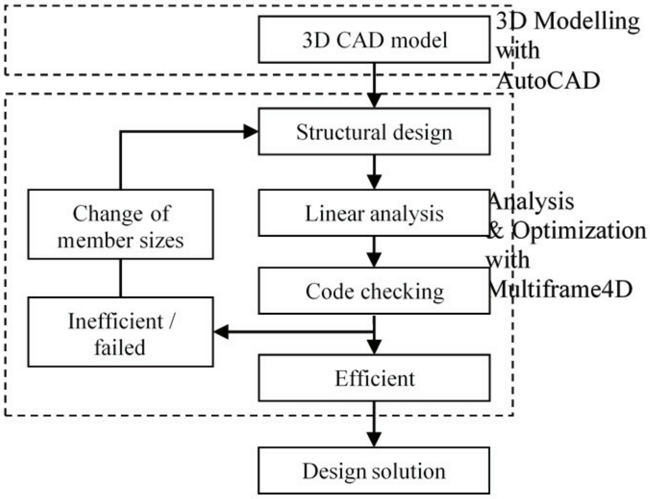

Fig. 2. Two computational methods involved in this research.

- CAD modelling using AutoCAD software
  AutoCAD is utilized to create 3D wireframe models of perimeter structure with different granularities.
- Discrete size optimization with Multiframe4D software
  Multiframe4D is used to produce a feasible and optimum structure from each imported AutoCAD wireframe model, through repeated cycle of linear analysis, code checking, and changing of member sizes. Each structural design solution is optimized with discrete size optimization method by changing of member sizes provided in discrete section library until the minimum weight of the structure is achieved. For each optimization cycle, the linear analysis is used to define member forces, deflection, and efficiency expressed as a percentage of member capacity used in the design, towards a predefined user code (Fig. 3). User code is set as a requirement to design all structural members to satisfy the limit of axial forces, bending, and combined stresses, while ignoring the slenderness limit. Automatic design feature and manual modification are used to vary the member sizes with an objective to achieve an overall efficiency closest to 100%.

4. Results

4.1. Medium-rise case

To examine the performance of the structural patterns towards vertical loads, three distinct granularities of triangular pattern are applied on the perimeter of medium-rise structures. The vertical impose loads are calculated as a uniform distributed loads of 3kPA, by taking into account that perimeter frame is working together with the central core in resisting the loads. By assuming that only half of the loads go to perimeter frame, the area of loads supported by perimeter structure is shown in Fig. 4.a. These loads are applied on each joints of the triangular pattern (Fig. 4.b), and being considered in the structural analysis and optimization process. For economic consideration, the structural members are grouped every 4 stories.

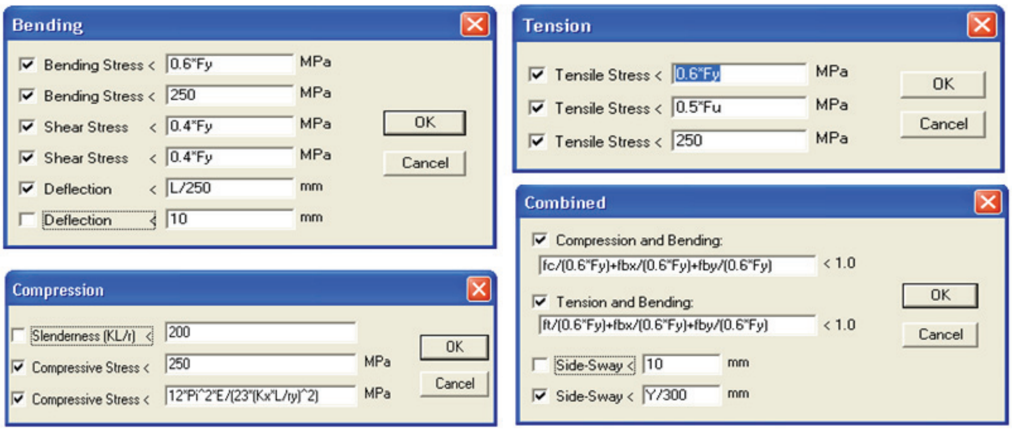

Fig. 3. The predefined user code used in optimization with Multiframe4D.

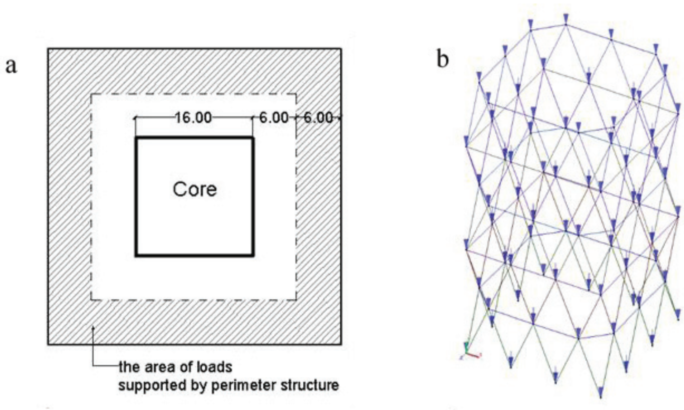

Fig. 4. (a) The area of vertical imposed loads supported by the perimeter structure; (b) Point loads applied on the medium-rise model.

The optimum perimeter structures with three distinct granularities for medium-rise case and comparison of the alternatives' attributes are shown in Fig. 5 and Table 1.

Table 1. Attributes of medium-rise case structures.

	Alternative 1 with 4-story triangles	**Alternative 2 with 2-story triangles**	**Alternative 3 with 1-story triangles**
Total mass	107767.37 kg	191258.52 kg	185520.74 kg
Average efficiency	68.56%	61.97%	59.21%
Number of joints	72	264	1008
Number of members	180	720	2880

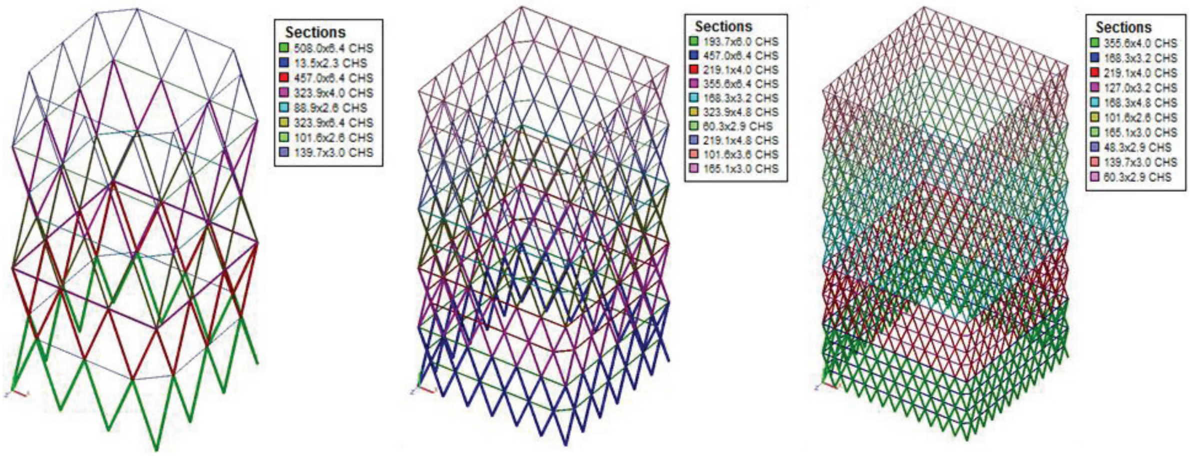

Fig. 5. 3D models of medium-rise case structures (alternative 1, 2, 3 from left to right).

Result shows that in term of structural efficiency, Alternative 1 has the least weight (with the total mass almost half the total mass of Alternative 2 or 3), which means it is the most efficient pattern. Further examination shows that the average efficiency of the structures (average of members' strength used in resisting loads) is decreasing from Alternative 1 to Alternative 2, and to Alternative 3. This is possibly caused by more members in Alternative 2 and 3, since it is impossible to use 100% strength of each member in the structure. In term of construction economy, grouping of member sizes are applied every 4 stories, thus the smaller the triangular pattern (denser granularity) means more member sizes are rounded to the biggest size every 4 stories. This may cause Alternative 1 to have highest average efficiency, while Alternative 3 has lowest average efficiency. However, the difference is not significant, meaning even if Alternative 2 and 3 are optimized further to reach average efficiency similar to Alternative 1, total mass of both alternatives will still be higher than Alternative 1. Hence, it is concluded that to resist vertical loads, triangular pattern with biggest granularity (Alternative 1) is the optimum.

Looking at the small difference between total mass and average efficiency of members from Alternative 2 and 3, it is considered that in denser granularities (pattern with smaller size of triangles), the changing of structural pattern's granularity does not have significant impact to the performance of structural pattern. However, considering large amount of joints and members in Alternative 3, Alternative 2 is still considered to be a better solution in term of economy of the construction.

4.2. High-rise case

To investigate the performance of triangular pattern towards lateral loads, the wind pressures on windward walls are considered as the lateral loads, and calculated based on Australian Standard. Considering that the perimeter structure is working together with the central core in resisting lateral loads, it is assumed that only 60% of the loads are taken by perimeter structure, while 40% of the loads are resisted by the central core. Assuming the role of floor diaphragm to distribute loads into two sidewalls, in the modelling process, the lateral loads are applied as point loads on joints of the sidewalls (Fig. 6). Here, the member sizes are grouped every 12 stories for economic consideration.

The optimum perimeter structures with three distinct granularities for high-rise case and comparison of the alternatives' attributes are shown in Fig. 7 and Table 2.

Table 2 shows that in term of efficiency criterion, Alternative 2 has the least weight, even with the least average efficiency of members. This means that if Alternative 2 is optimized further to reach the same efficiency as Alternative 1, it is possible that Alternative 2 has less weight. Thus, it is concluded that Alternative 2 is the optimum pattern. Further observation shows that the total mass and average efficiency of Alternative 2 and 3 are quite similar, showing that in resisting lateral loads, triangular pattern with smaller granularities have better performance.

However, unlike in medium-rise case, where the most efficient alternative has almost half the weight of other alternatives, in high-rise case, the total mass of three alternatives are not significantly different. The total mass of Alternative 2 with the least weight, compared to Alternative 1 with the highest weight, only differs by 7%.

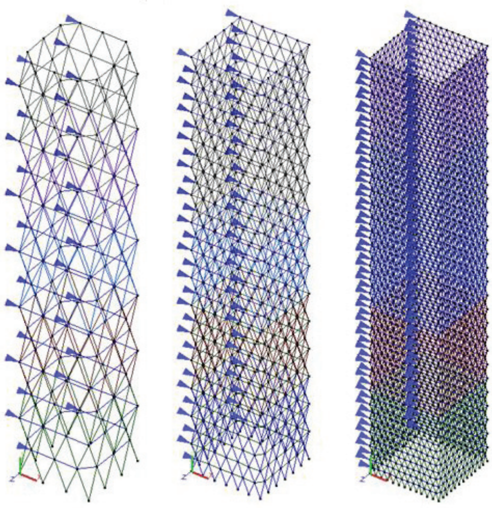

Fig. 6. Point loads applied on the three high-rise models observed (alternative 1, 2, 3 from left to right).

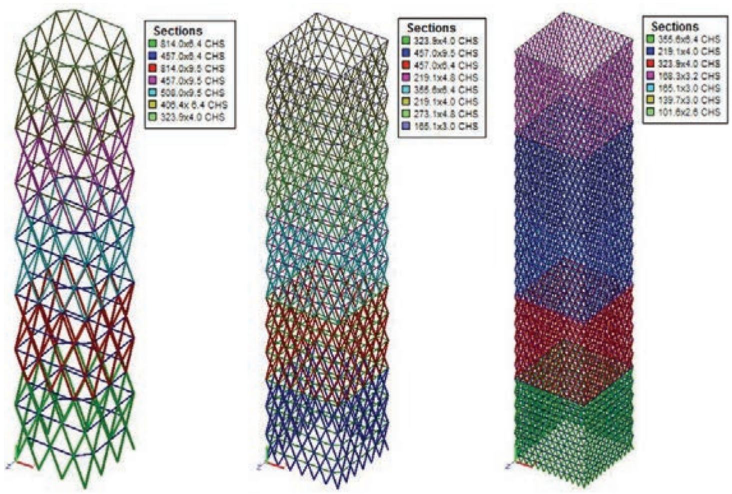

Fig. 7. 3D models of high-rise case structures (alternative 1, 2, 3 from left to right).

Table 2. Attributes of high-rise case structures.

	Alternative 1 with 4-story triangles	Alternative 2 with 2-story triangles	Alternative 3 with 1-story triangles
Total mass	891209.83 kg	825433.54 kg	829838.03 kg
Average efficiency	75.28%	66.01%	66.84%
Number of joints	192	744	2928
Number of members	540	2160	8640

5. Discussion

This research is performed to examine the influence of granularity variation of structural pattern on the perimeter of vertical structure, towards its structural performance. Several founding from the research are below:

- In resisting vertical loads (medium-rise case), triangular pattern with largest granularity (pattern with 4-story triangles) is the optimum. Perimeter structure modelled with this pattern has the least weight, with total mass around 55-60% of two other alternatives.
- In resisting lateral loads (high-rise case), triangular pattern with medium granularity (pattern with 2-story triangles) is the optimum. However, the weight is not significantly reduced, showing that for resisting lateral loads, changing of structural pattern's granularity has minor impact towards efficiency of the structure.
- Average efficiency of the members tends to decrease in denser granularity (pattern consisting smaller triangles), since structure with smaller granularity has larger amount of members. Thus, more members mean more rounding up of member sizes has been performed due to economic consideration (grouping members every 4 or 12 stories).

Overall, this research confirms that greater granularity is more efficient for resisting vertical loads. While for lateral loads, variation of granularity has no significant impact to the structural efficiency, although smaller granularity tends to perform better. Further research needs to be carried out to confirm this result, and also to see whether this only applies for triangular pattern, or for certain form of the triangular pattern.

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