DIGITAL & EMPATHIC ARCHITECTURE CIVIL ENGINEERING INTERNATIONAL CONFERENCE

BOOK OF ABSTRACT

20-21 AUGUST 2021

Sponsored By:

FOREWORD

Dear Colleagues,

Dear Friends,

On behalf of the organizing committee, we would like to extend our warmest welcome to you to the Digital & Empathic Architecture & Civil Engineering (DEACE) International Conference.

DEACE International Conference and International Student Workshop on Bamboo Gridshell Computational Design are Virtual Events being held by the Faculty of Civil Engineering & Planning as a series of events celebrating the 60th Anniversary Petra Christian University, "The Rock Turns Diamond!"

DEACE aims to gather researchers, scholars, and practitioners all over the world to share and exchange their knowledge and breakthrough in the fields of Architecture and Civil Engineering especially toward the new era.

We would like to thank all keynote speakers, workshop speakers, scientific committee, session chairs, authors/presenters, participants, sponsors, conference & workshop coordinators, and everybody who has all contributed to this conference with great efforts for months.

We do hope that you enjoy your attendance at the DEACE 2021!

Dr. Rudy Setiawan

Chair of Organizing Committee DEACE 2021

KEYNOTES SPEAKERS

Prof. Dr. Djwantoro Hardjito
Petra Christian University

Prof. Djwantoro Hardjito is currently a professor at the Civil Engineering Department, Petra Christian University, Surabaya, Indonesia. Concurrently, he is also the rector of the university since 2017. Prior to joining Petra, he was affiliated with Curtin University, Malaysia, for five years until 2009. He was the recipient of Australian Development Scholarship Award to pursue his doctoral degree at Curtin University, Australia, and Japan-ADB Scholarship Award for his Master's degree at Asian Institute of Technology, Thailand. His research interest is in the area of geopolymer concrete and the use of waste as construction materials. He has published more than 50 scientific articles in international journals and conference proceedings. He has received several invitations to deliver keynote speeches in international conferences.

Prof. Andrew Charleson
Victoria University of Wellington, New Zealand

Andrew Charleson has recently retired as an Associate Professor, School of Architecture, Victoria University of Wellington, New Zealand. He has taught the subject of architectural structures in lecture and studio settings for over 30 years. During this time, he has won several teaching awards, including a National Tertiary Teaching Excellence Award for Excellence in Innovation.

Andrew has two main strands of research interest. The first strand, how structure can enrich architecture, was brought together in the book Structure as Architecture: a Source Book for Architects and Structural Engineers. The first edition was published by Elsevier in 2005, and the second by Routledge in 2014. Andrew is currently working with a landscape architect on another book, Structures in the Landscape.

The second research strand relates to earthquake engineering. In 2008 his book Seismic Design for Architects: Outwitting the Quake was published by Elsevier, and he is the co-author of Seismic Isolation for Architects, published by Routledge in 2016.

In his retirement, Andrew is a voluntary visiting professor in schools of architecture. So far, he has visited universities in Indonesia, Albania, Croatia and Serbia.

Back in the early 1980's Andrew and his family lived in Bandung for over two years. Andrew was part of a bi-lateral aid project to introduce Indonesia's first seismic code. He worked in the DPMB, now called PUSKIM.

Prof. Dr. Janice Rieger
Queensland University of Technology, Australia

Dr Janice Rieger is a Senior Lecturer in the School of Design, Creative Industries Faculty at QUT, Australia. She has sixteen years of international post-secondary teaching experience, over five years in museum and gallery studies and fifteen years of experience in design. Her research in history, theory and criticism looks at the relationship between disability, design and material culture from a spatial perspective. Janice is a Chief Investigator with the Centre for Justice and the Design Lab at QUT. She is also the QUT Research Ethics Advisor at the School, Faculty and University Level and a Senior Fellow with the Higher Education Academy, UK. Dr Rieger has served as a faculty member at the University of Calgary, (Calgary, Canada), York University (Toronto, Canada), Mount Royal University (Calgary, Canada), and the University of Alberta (Edmonton, Canada). She has been a visiting scholar at the University of Hasselt (Hasselt, Belgium) and L'Université Catholique de Lille (Lille, France). From her advocacy with people with disabilities, she was awarded a Mayor's Award, Government of Alberta State-wide Award and was recently invited to be the first overseas member of the European Institute for Design and Disability. In Canada, she co-founded a national certificate program in accessible housing design (CSAHD). Her work in inclusive design has led to code, policy, curriculum and legislative changes in Australia, North America and Europe. Dr Rieger is on the editorial board for the European Society for Disability Research (ALTER, Elsevier), and co-facilitated the 2018 International Disability Mundus doctoral school in France. Dr Rieger is also on the Scientific Advisory Board for Applied Human Factors and Ergonomics (AFHE), USA. Her research focuses on creating cultures of inclusion and her recent publications were featured in The Routledge Handbook of Disability Arts, Culture and Media (2019), Space and Culture (2019) and CoDesign - International Journal of CoCreation in Design and the Arts (2019).

Prof. I-Tung Yang, Ph.D.

National Taiwan University of Science and Technology, Taiwan

Professor I-Tung Yang obtained his Ph.D. in Civil and Environmental Engineering from The University of Michigan, Ann Arbor in 2002. Previously, he held a master's degree in industrial and Operations Engineering and Construction Engineering and Management from the same institute.Professor I-Tung Yang specialties in Construction Management, Computational Intelligence, Decision-making and Risk Analysis, and Information Technology has brought him to be the Chair, Department of Civil and Construction Engineering at the National Taiwan University of Science and Technology from 2018 up to the present, as well as Professor in Department of Civil and Construction Engineering Specialty. He has also been the president of Taiwan Construction Research Institute from 2015-2018.Professor I-Tung Yang also contributes to larger scaled education development, by becoming an associate editor in KSCE Journal of Civil Engineering, Grant Proposal Review Board, Ministry of Science and Technology, Taiwan, Co-investigator, National Energy Program, Taiwan, and become a member of the review board in many international journals. He is also a member of the International Science Committee in the International Symposium on Reliability Engineering and Risk Management.He is also the chair of Chinese Taipei APEC Engineer/IntPE Monitoring Committee, Information Technology Committee, Chinese Institute of Civil Hydraulic Engineering, Disaster Mitigation Committee - Chinese Institute of Engineers, and member board and committee in many civil engineering institutes.

Dr. Wen-Shao Chang

University of Sheffield, UK

Dr. Wen-Shao Chang joined the Sheffield School of Architecture in 2017, and he is now Director of Postgraduate Research Programme. Prior to joining SSoA, he worked for the Kyoto University, Japan, as a JSPS Fellow and the University of Bath as a lecturer. He has a dual background in Architecture and Structural Engineering, and hold the degrees of BS Arch, MS Arch and PhD from National Cheng Kung University, Taiwan. His research interest is in exploring natural materials utilisation and strategies to achieve low impact in buildings. In SSoA, he is part of People, Environment and Performance (PEP) research group. His full biography can be seen on the SSoA website: https://www.sheffield.ac.uk/architecture/people/academic-staff/wen-shao-chang

Esti A.Nurdiah, Ph.D. (cand)

Petra Christian University, Indonesia

Esti Nurdiah is a lecturer at the Department of Architecture, Petra Christian University, Surabaya, Indonesia. She was graduated from Universitas Gadjah Mada and completed her master degree at Institut Teknologi Sepuluh November, Indonesia. Currently, Esti is studying at Sheffield School of Architecture for her PhD in Architecture, and for her study, she is sponsored by Indonesia Endowment Fund for Education (LPDP). Through her research, she aims to explore the utilisation of bamboo for gridshell structure by analysing the material, structural morphology, forces and construction methods.

Wong Foek Tjong, Ph.D.

Petra Christian University, Indonesia

Dr. Wong Foek Tjong is currently an associate professor at the Department of Civil Engineering, Petra Christian University, Surabaya. He received his Ph.D. degree from Asian Institute of Technology, Thailand in 2009. His research interests include developments and applications of finite element methods for static, dynamic, and stability analyses of structures, and structural optimizations. He has published tens of scientific articles in international journals and conference proceedings. (ID Scopus 26530527000, Google ID nCVRs_4AAAAJ). Email wftjong@petra.ac.id

COMMITTEE

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SCHEDULES

Schedule Conference Day 1 – August 20th, 2021

<table>
<tr><td rowspan="9">Keynote Session</td><td>07:30-08:00</td><td colspan="2">Participants enter the zoom meeting
Link : https://petra.id/DEACE-DAY1
Passcode : DEACE2021</td></tr>
<tr><td>08:00-08:10</td><td colspan="2">Conference Opening – Greetings and Prayer</td></tr>
<tr><td>08:10-08:20</td><td colspan="2">Welcoming Speech from Organizing Committee Chairman and The Dean of The Faculty of Civil Engineering and Planning
Dr. Rudy Setiawan</td></tr>
<tr><td>08:20-08:30</td><td colspan="2">Profile Video of The Faculty of Civil Engineering and Planning + Conference Day 1 Photo Session</td></tr>
<tr><td>08:30-09:45</td><td colspan="2">Keynote Session I - Prof. Dr. Djwantoro Hardjito
(08.30 – 09.15 : Presentation → 09.15 – 09.45: Q&A Session)</td></tr>
<tr><td>09:45-10:00</td><td colspan="2">Sponsor Session -</td></tr>
<tr><td>10:00-10:15</td><td colspan="2">Break</td></tr>
<tr><td>10:15-11:30</td><td colspan="2">Keynote Session II - Prof. Andrew Charleson
(10.15 – 11.00 : Presentation → 11.00 – 11.30: Q&A Session)</td></tr>
<tr><td>11:30-12:45</td><td colspan="2">Lunch Break</td></tr>
<tr><td rowspan="7">Parallel Session</td><td>12:45-13:00</td><td>Zoom General Room</td><td>Participants enter the zoom meeting
Link : https://petra.id/DEACE-DAY1
Passcode : DEACE2021
Please change your username so we can move you to the correct breakout room</td></tr>
<tr><td rowspan="2">13.00-15.00</td><td>Breakout Room 1</td><td>Parallel Session 1
Civil Engineering Paper (details on p.15)
Sub-theme: Structural Engineering and Materials</td></tr>
<tr><td>Breakout Room 2</td><td>Parallel Session 1
Architectural Paper (details on p.16)
Sub-theme: Building Science and Technology</td></tr>
<tr><td>15.00-15:15</td><td colspan="2">Back to Zoom general room, break
Please change your username so we can move you to the correct breakout room</td></tr>
<tr><td rowspan="2">15.15-17.15</td><td>Breakout Room 1</td><td>Parallel Session 2
Civil Engineering Paper (details on p.17)
Sub-theme: Construction Management</td></tr>
<tr><td>Breakout Room 2</td><td>Parallel Session 2
Architectural Paper (details on p.18)
Sub-theme: Architecture and Urban Development</td></tr>
<tr><td>17.15</td><td colspan="2">The first day of the conference is over</td></tr>
</table>

Schedule Conference Day 2 – August 21st, 2021

Parallel Session	07:30 - 08:00	Zoom General Room	Participants enter the zoom meeting Link : https://petra.id/DEACE-DAY2 Passcode : DEACE2021
	08.00 – 09.15	Prayer **Keynote Session III** – *Prof. I Tung Yang, Ph.D.* (08.00 – 08.45 : Presentation → 08.45 – 09.15: Q&A Session)	
	09.15 – 09.30	**Sponsor Session –** Assign to breakout room	
	09.30 - 11.30	Breakout Room 1	**Parallel Session 3** **Civil Engineering Paper** (details on p.19) Sub-theme: Structural Engineering and Materials
		Breakout Room 2	**Parallel Session 3** **DEACE Student Workshop Presentation** (details on p.20)
	11.30 – 12.30	Break, All participants back to zoom general room	
	12.30 – 14.30	Breakout Room 1	**Parallel Session 4** **Civil Engineering Paper** (details on p.21) Sub-theme: Transportation
		Breakout Room 2	**Parallel Session 4** **DEACE Student Workshop Presentation** (details on p.20)
Keynote Session	14.30 – 14.45	Break, All participants back to zoom general room Link : https://petra.id/DEACE-DAY2 Passcode : DEACE2021	
	14:45 – 16.00	**Keynote Session IV** – *Prof. Dr. Janice Rieger* (14.45 – 15.30 : Presentation → 15.30 – 16.00: Q&A Session)	
	16.00 – 16.30	**Closing Session** The announcement of Best Paper and Best Workshop Design Conference Photo day 2 – Winners Photo group Closing Remarks	

Parallel Session 1 – Breakout Room 1

BR 1 - Civil Engineering		Moderator	Wong Foek Tjong, Ph.D.	
		Subtheme	Structural Engineering and Materials (A1)	
Date	**Time**	**Paper ID**	**Title**	**Author**
20 August 2021	12.45 - 13.00	Registration		
	13.00 - 13.20	A1-1	A Comparative Study of Several Bio-Inspired Algorithms in Cost Optimization of Cellular Beams	Ansheilla Tjahjono, Evelyn Jane Wijayanti, Doddy Prayogo, Wong Foek Tjong
	13.20 - 13.40	A1-2	The Study of Shear Wall Use in Buildings during the Architecture Design Process	Livian Teddy, Husnul Hidayat, Dessa Andriyali A.
	13.40–14.00	A1-3	Modified Partial Capacity Design (M-PCD) Method	Levin Sergio Tanaya, Herryanto, Pamuda Pudjisuryadi
	14.00 - 14.20	A1-4	Comparison Reinforcement Design Shear Wall Modelling Planar and Assembly in Elevator Shaft	Daud Rahmat Wiyono, Roi Milyardi, Yosafat Aji Pranata, Anang Kristianto
	14.20 - 14.40	A1-5	A Comparative Study of Several Nature-Inspired Algorithms in Steel Deck Floor System Cost Optimization	Timothy Emanuel, Hadrian, Doddy Prayogo, Wong Foek Tjong
	14.40 - 15.00	A1-6	Review of Autonomous Self-Healing Cementitious Material	Sofian Arif Susanto, Antoni, Djwantoro Hardjito
	15.00	Back to main room, short break, preparation to the next parallel session 2		

- **Time for each paper includes the Q&A session**
- **Please follow this name format**
  - ✓ For Presenters : PAPER ID_Presenter name
  - ✓ For Participants : Participant_Your name

Parallel Session 1 – Breakout Room 2

BR 2 - Architecture		Moderator	Prof. Lilianny Sigit Arifin, Ph.D.	
		Subtheme	Building Science and technology (B1)	
Date	**Time**	**Paper ID**	**Title**	**Author**
20 August 2021	12.45 - 13.00	Registration		
	13.00 - 13.20	B1-1	Designing louvers toward optimum daylight performance in Indonesia: A parametric study	Rendy Perdana Khidmat, Hiroatsu Fukuda, Kustiani, Andi Prasetiyo Wibowo
	13.20 - 13.40	B1-2	The Importance of Iterative Process in Façade Design Optimization for a Green Office Building in South Tangerang City	Dian Fitria
	13.40–14.00	B1-3	Comparison of Shibataea kumasasa and Equisetum hyemale as vertical greenery system for thermal and light shade in student's architectural design studio in Surabaya	Luciana Kristanto, Wanda W.Canadarma, Elvina S.Wijaya
	14.00 - 14.20	B1-4	Experimental study on ventilation using earth-to-air heat exchange in Surabaya	Anik Juniwati, Danny Santoso Mintorogo, Azarya Ezra Abednego, Stevie Kurnoawan, Eka Dewi Handoyo
	14.20 - 14.40	B1-5	Comparison of simulation-based methods and metaheuristic optimization algorithms for optimizing window design by considering daylighting and heat transfer in tropical region of Indonesia	Aris Budhiyanto, Adrianto Oktavianus, Belinda Tedjokusumo, Kevin Harsono, I-Tung Yang
	14.40 – 15.00			
	15.00	Back to main room, short break, preparation to the next parallel session 2		

- **Time for each paper includes the Q&A session**
- **Please follow this name format**
  - ✓ For Presenters : PAPER ID_Presenter name
  - ✓ For Participants : Participant_Your name

Parallel Session 2 – Breakout Room 1

BR 1 - Civil Engineering		Moderator	Doddy Prayogo, Ph.D.	
		Subtheme	Construction Management (C)	
Date	**Time**	**Paper ID**	**Title**	**Author**
20 August 2021	15.00-15.15	Registration		
	15.15-15.35	C-1	Empowering Female Students to be Successful Professionals in the Construction Industry	Christina Liem, Riza Yosia Sunindjio, Cynthia Wang
	15.35-15.55	C-2	Intellectual Intelligence and Emotional Intelligence of Project Manager	Gregorio Reinaldo, Andi, Vincent Ong.
	15.55-16.15	C-3	Causes of Work Accidents and its Impact on the Road and Bridge Construction Projects	Josefine Ernestine Latupeirissa, Irwan Lie Keng Wong, Herby Calvin Paskal Tiyow
	16.15-16.35	C-4	Lean Construction and Project Performance in the Australian Construction Industry	Muhammad Fauzan, Riza Yosia Sunindijo
	16.35 -16.55	C-5	Actual and Expected Transactional and Transformational Leadership Behaviors of Project Managers	Andi, Kevin Sugianto, Arsenius Felix Khoesasih
	16.55 – 17.15	C-6	A preliminary survey on the understanding and application of digital and emphatic engagement of the construction constituents in Surabaya	Paulus Nugraha , M Jonathan , A Listio .
	17.15	The first day of the conference is over		

- **Time for each paper includes the Q&A session**
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Parallel Session 2 – Breakout Room 2

BR 2 - Architecture		Moderator	Timoticin Kwanda, Ph.D.	
		Subtheme	Architecture and Urban Development (B2)	
Date	**Time**	**Paper ID**	**Title**	**Author**
20 August 2021	15.00-15.15	Registration		
	15.15-15.35	B2-1	The Uniformity Concept of Urban Design: Impact of Cultural Traditions on the Meaning of Balinese Town	Eka Diana Mahira, Bambang Soemardiono, Eko Budi Santoso
	15.35-15.55	B2-2	Reinterpreting local wisdom of Rumah Kaki Seribu as sustainable architecture	Livia Hariyanto, Bagas Cahya Prabaswara, Lilianny Sigit Arifin
	15.55-16.15	B2-3	An investigation into the effectiveness of student-led experiential learning for UG architects and the implications of incorporating AR into such pedagogical exercises.	Matthew Wallwork, Mia Tedjosaputro, Weishun Xu
	16.15-16.35	B2-4	A Study of Place Senses in Museum Online-visits	Rully Damayanti, Bramasta Putra Redyantanu, Florian Kossak
	16.35 -16.55			
	16.55 – 17.15			
	17.15	The first day of the conference is over		

- **Time for each paper includes the Q&A session**
- **Please follow this name format**
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Parallel Session 3 – Breakout Room 1

BR 1 - Civil Engineering		Moderator	Hartanto Wibowo, Ph.D.	
		Subtheme	Structural Engineering and Materials (A2)	
Date	**Time**	**Paper ID**	**Title**	**Author**
21 August 2021	09.15 - 09.30	Registration		
	09.30 - 09.50	A2-1	Alternative Approach in Partial Capacity Design	Herryanto, Levin Sergio Tanaya, Pamuda Pudjisuryadi
	09.50 - 10.10	A2-2	The Effect of Crumb Rubber in Dense Graded and Open Graded Cold Mixture Asphalt	Paravita Sri Wulandari, Daniel Tjandra
	10.10 - 10.30	A2-3	Modeling and Analysis of 3D-Printed Reinforced and Prestressed Concrete Beams	Jimmy Chandra, Hartanto Wibowo, Darwin Wijaya, Fransisca Oktaviani Purnomo, Pamuda Pudjisuryadi, Antoni
	10.30 - 10.50	A2-4	Optimization of Concentrically Braced Steel Frame Structures Based on SNI 1726:2019, SNI 1727:2020, and AISC 341-16	Jonathan Aloysius, Juan Antonio Sumito, Doddy Prayogo, Hasan Santoso
	10.50 - 11.10	A2-5	Investigation of the Material Mixtures and Fiber Addition for 3D Concrete Printing	Antoni, Audi Agraputra, Daniel Teopilus, Axelino Hadi Sunaryo, Malvin Manuel Mulyadi, Pamuda Pudjisuryadi, Jimmy Chandra, Djwantoro Hardjito
	11.10 - 11.30			
	11.30 –12.30	Break, All participants back to zoom general room		

- **Time for each paper includes the Q&A session**
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Parallel Session 3 – Breakout Room 2

BR 1 - Architecture		Moderator	Rully Damayanti, Ph.D.
		Subtheme	Bamboo Gridshell Computational Design (E)
Date	**Time**	**Presenter**	**Reviewer**
21 August 2021	09.15 - 09.30	Registration	
	09.30 – 10.00	Group 1A	Group 3B
	10.00 - 10.30	Group 2A	Group 1B
	10.30 – 11.00	Group 3A	Group 2B
	11.00 - 11.30	General overview from Lecturers	
	11.30 –12.30	Break, All participants back to zoom general room	

Parallel Session 4 – Breakout Room 2

BR 1 - Architecture		Moderator	Rully Damayanti, Ph.D.
		Subtheme	Bamboo Gridshell Computational Design (E)
Date	**Time**	**Presenter**	**Reviewer**
21 August 2021	12.15 - 12.30	Registration	
	12.30 – 13.00	Group 1B	Group 3A
	13.00 – 13.30	Group 2B	Group 1A
	13.30 – 14.00	Group 3B	Group 2A
	14.00 - 14.30	General overview from Lecturers	
	14.30 –14.45	Break, All participants back to zoom general room	

Please follow this name format

- For Workshop Group : E_Group code_Your name
- For Workshop Audience : Participant_Your name

Parallel Session 4 – Breakout Room 1

BR 1 - Civil Engineering		Moderator	Kardi Teknomo, Ph.D.	
		Subtheme	Transportation (D)	
Date	**Time**	**Paper ID**	**Title**	**Author**
21 August 2021	11.30 - 12.30	Registration		
	12.30 - 12.50	D-1	Changes in Drivers' Viewing Frequency, Maneuver Duration, and Degree of Difficulty During Back-in Parking Maneuver with Different Conditions of Parking Spaces	Rudy Setiawan, Arcelina Saputri Dammara, Billy Cahyadi, Bryan Widarno, Fillbert Hanselly Njoko, Maria Noviani
	12.50 - 13.10	D-2	Sustainable Road-Kill Mitigation in Gladak Perak Bridge at Lumajang, Indonesia	Paravita Sri Wulandari, Hansen Richardo Lestyana, Johnson, Jason F. Tranggono
	13.10 - 13.30	D-3	Probability of Willingness to Pay Road Pricing Based on the Perspective of Households in Jakarta	Melchior Bria, Ludfi Djakfar, Achmad Wicaksono
	13.30 - 13.50	D-4	Potential Damage to Residential Building due to Adjacent Surcharge Fill Loading – Case Studies in Surabaya - Indonesia	Daniel Tjandra, Handoko Sugiharto, Januar Buntoro, Paravita Sri Wulandari
	13.50 – 14.10			
	14.10 - 14.30			
	14.30 –14.45	Break, All participants back to zoom general room		

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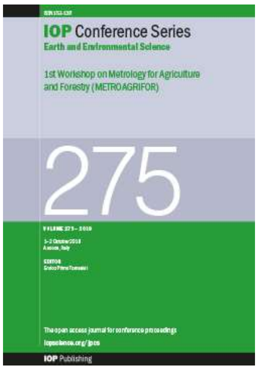

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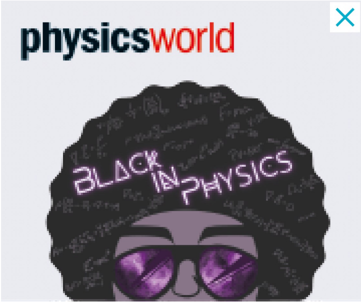

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Investigation of the material mixtures and fiber addition for 3D concrete printing

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Abstract. The era of Construction 4.0 is characterized by technological advances used in the construction industry. One of the advancements is the use of 3D concrete printing in construction. However, until now, the development of 3D concrete printing in Indonesia is still minimal. The main challenge is to determine the composition of the material mixtures for making the mortar, having good extrudability but still has sufficient strength. The rapid initial setting time required was also different for the concrete for typical construction. Our previous mixture composition incorporating calcium oxide to accelerate the initial setting time was adequate. However, the extrusion process was still not satisfactory. In this study, the effect of cement to sand ratio, sand particle size, and the addition of synthetic micro-fiber was investigated on the main properties of 3D printing materials, i.e., initial setting time, flowability, extrudability, and compressive strength. It was found that using smaller maximum particle size sand increases the initial setting time. The addition of synthetic microfiber reduces the strength and the workability of the mortar. However, fiber inclusion has advantages as it reduces the possibility of cracking in the printed concrete. The extruded concrete specimens were shown to have significant strength reduction due to lack of compaction, and it was affected by the direction of printing showing orthotropic properties of the 3D printed concrete.

1. Introduction

Amid fast-paced technological advances, the construction sector has begun to adopt current technology, which can increase the productivity and quality of the products produced. One of the technologies that are developing and used is additive manufacturing, or what is commonly known as 3D concrete printing. In Indonesia, 3D concrete printing technology is uncommon in construction activities, in contrast to the developed countries. Developments related to 3D concrete printing technology, both in terms of tools and materials, have enormous potential so that this technology can be used collectively in the future.

Over the last few decades, 3D printing technology has attracted the world's attention because of its ability to convert computer drawings into real objects [1]. The advantage of 3D concrete printing technology is that it can make concrete elements or structures without using formwork. The costs incurred can be more reduced, especially for high complexity and irregular shapes.

The characteristics that need to be considered for the 3D concrete printing materials are extrudability and buildability [2,3]. Extrudability is the material's ability to get printed out of the pump without obstruction and maintained a shape consistent with the shape of the nozzle. Buildability is the ability of a material to maintain its shape while withstanding the load of the subsequent layer. It is necessary to have a collection of admixture and supplementary cementitious material so that the fresh and hardened characteristics of the concrete can be modified easily to achieve extrudable and buildable material.

In general, 3D concrete printing materials use a high cement to sand ratio, resulting in the concrete having excessive compressive strength and expensive costs. The previous study conducted by Antoni et al. [4] experienced several problems, such as unsatisfactory extrusion process and cracks in the 3D printing material. The cracks that occur were found in the second layer and so on. This could be due to the uneven surface of the previous layer. Cracks in hardened concrete could also be because of the higher shrinkage of the concrete due to high cement content.

In this study, the cement to sand ratio was reduced to reduce the cost of the material. Synthetic microfiber was used to reduce crack problems. This study aimed to investigate the effect of the cement-to-sand ratio, the maximum particle size of the sand, and the addition of synthetic micro-fiber on the fresh and hardened concrete. The tests that were carried out were workability, initial setting time, extrudability, and compressive strength. The compressive strength of the cube specimens was also compared to the extruded samples.

2. Materials and mixtures

The materials used were silica sand, calcium oxide (CaO), Portland cement, synthetic micro-fiber, and admixtures such as accelerators and superplasticizers. Portland composite cement (PCC) was obtained from Semen Indonesia. The PCC has a specific gravity of 3.15 measured based on ASTM C188 [5], and the normal consistency test of the PCC was measured at a water-to-cement ratio of 0.33 based on standards ASTM C187 [6]. The use of graded silica sand was intended to ensure consistent workability. In this study, two gradations of the silica sand were used, with a maximum size of 0.425 mm and 0.150 mm. The use of CaO was chosen to accelerate the initial setting time of the concrete. The silica sand and CaO was obtained from the Tuban quarry, East Java.

The addition of polypropylenes micro-fiber (diameter of 0.3 mm and length of 6 mm) was intended to reduce cracks in the extruded concrete. The fiber used was 0.3% mass of the total mixture. The admixtures used were superplasticizer (Sika Viscocrete 1003) and accelerator (SikaCim). The superplasticizer was added as much as 1% of the cement mass to obtain a flow diameter of 15 cm to 21 cm, based on Tay, Qian, et al. [8]. The CaO of 10% and accelerator of 4% of the cement mass are based on Antoni et al. [4]. The accelerator was used to increase workability and get a faster initial setting to get a better buildability.

The mix design is shown in Table 1. Notations “B” and “K” were for the maximum particle size of 0.425 mm and 0.150 mm. The following code was for the mass ratio of cement (C), sand (S), and also “F," denoting the addition of polypropylene synthetic micro-fiber in the mixture.

Table 1. Mix design for the 3D printed concrete for one cube specimen.

Mixture code	Max sand particle size	w/c	Cement (gr)	Sand (gr)	PP fiber (gr)	Sp (gr)	Cao (gr)	Accelerator (gr)
B_C3S2	0.425 mm	0.3	147	98	0	1.47	14.7	5.9
B_C3S2_F		0.3	147	98	0.9	1.47	14.7	5.9
B_C1S1		0.3	122.5	122.5	0	1.22	12.2	4.9
B_C1S1_F		0.3	122.5	122.5	0.9	1.22	12.2	4.9
K_C3S2	0.150 mm	0.3	147	98	0	1.47	14.7	5.9
K_C3S2_F		0.3	147	98	0.9	1.47	14.7	5.9
K_C1S1		0.3	122.5	122.5	0	1.22	12.2	4.9
K_C1S1_F		0.3	122.5	122.5	0.9	1.22	12.2	4.9

2.1. Equipment

The 3D concrete printing equipment in this research was modeled using a mortar extruder. The equipment for the material testing is shown in Figure 1. The plywood table was used to secure the concrete extruder, and the extrusion process was carried out from the top of the table. The moving bed consists of several multiplex stacks that can be adjusted in number to adjust the distance of the concrete printed from the nozzle and the printing bed itself. This simple contraption was used before using machine-controlled movement that was currently still in the construction process.

The concrete extruder uses a nozzle on its end with four types of nozzles (Figure 2). These nozzles have different hole areas, so differences in the extrusion process can be analyzed with different nozzle shapes and areas. The A nozzle has an opening area of 9 cm^2 (6×1.5 cm), the B nozzle has an opening area of 6 cm^2 (4×1.5 cm), the C nozzle has an opening area of 3.14 cm^2 (ϕ2 cm), and the D nozzle has an opening area of 1.57 cm^2 (ϕ1 cm).

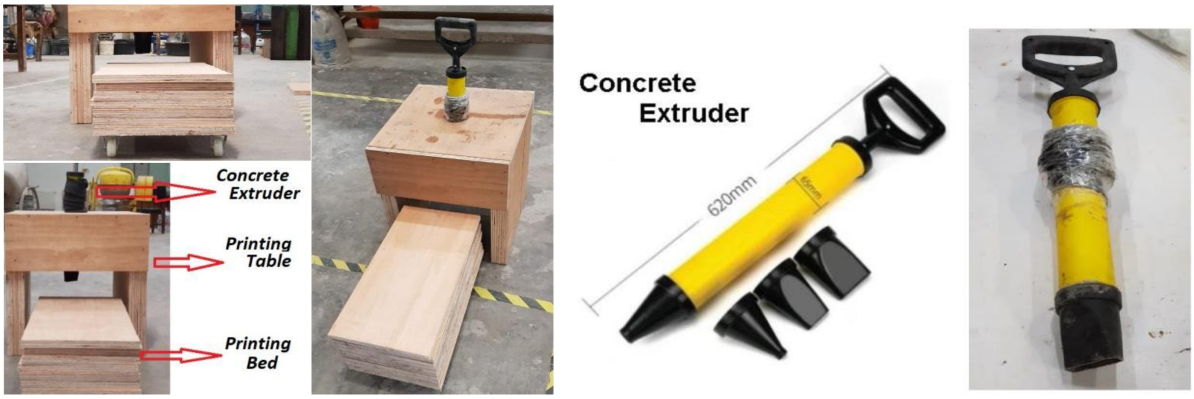
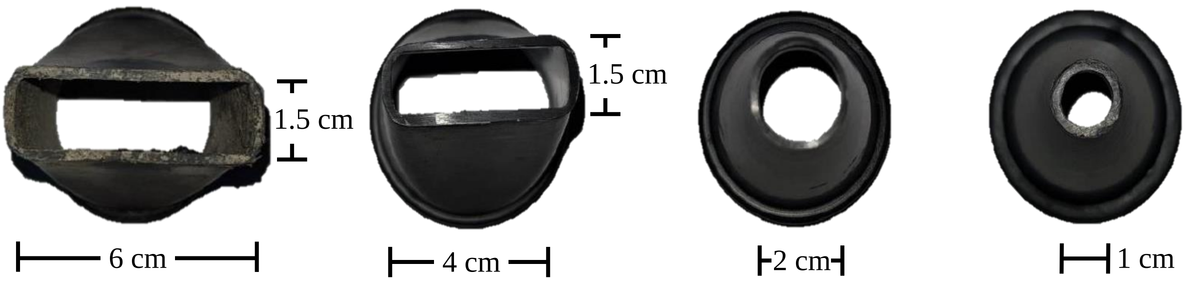


Figure 1. 3D printing equipment model.



(a) Nozzle A (b) Nozzle B (c) Nozzle C (d) Nozzle D

Figure 2. Nozzle size and shape for the extrudability test.

2.2. Mixing method

The mixing process was started by dry mixing the cement and sand evenly, and then water was poured into the mixture and then stirred using a handheld mixer. Accelerator and superplasticizer were added to the prepared mixture slowly while still stirring the mixture. Then, calcium oxide was added to the mortar mixture, and lastly, synthetic micro-fiber was added and mixed until homogenous.

2.3. Testing

The initial setting time of fresh concrete using a penetrometer based on ASTM C403 [10]. The initial setting time suitable for 3D concrete printing is under 90 minutes [11]. The workability of the mortar was measured in the flow table test method based on ASTM C230 [12]. A recommended flow diameter for 3D concrete printing is between 13 cm to 21 cm [8]. The compressive strength test was carried out on a hardened concrete cube with a 5 cm based on ASTM C109 [13]. The compressive strength tests were done on the 3, 7, 14, and 28 days with three replications.

An extrudability test was carried out to evaluate the process of printed concrete from the nozzle. The consistency of the extruded concrete through the nozzle and the hardened concrete was observed. This test was only done for the concrete mixture with the highest flow diameter but under 21 cm. In this study, the B_C1S1 and B_C1S1_F mixtures were chosen for the extrudability test. The test was carried out with a constant distance of 3 cm between the nozzle and the printing bed.

The compressive strength test was also performed on the extruded samples by cutting them into several parts at 28 days. The given compressive load is divided into two directions, namely parallel to the cross-section of the layer (pl) and perpendicular to the cross-section of the layer (pp), as shown in Figure 3. This division was based on the surface of the layer. The flat surface was tested with load directed parallel to the cross-section of the layer. In contrast, the uneven or irregular surface was tested with load directed perpendicular to the cross-section of the layer. The compressive strength was calculated from the average value of the cut specimens.

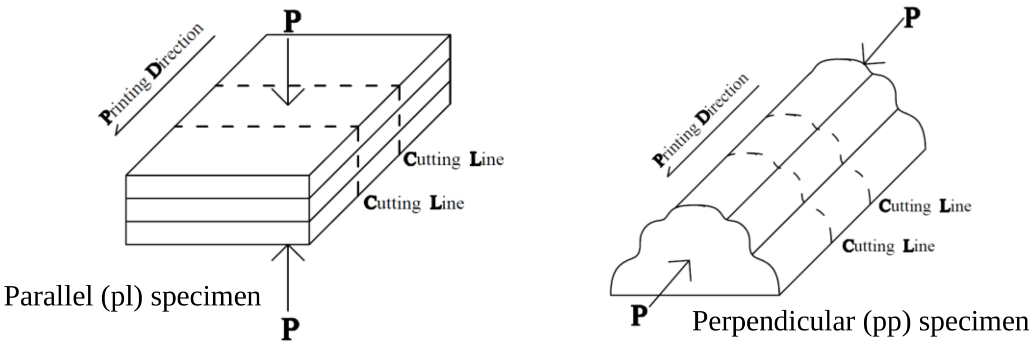


Figure 3. Compression load given directed parallel (pl) and perpendicular (pp) to the cross-section.

3. Result and discussion

3.1. Workability

Workability test was done by testing the flow diameter of each mix design combination based on ASTM C230 / C230M-03 [12]. The larger the diameter of the flow, the higher the workability of the concrete, which means that the concrete will flow more quickly in the pump. The feasible flow diameter for the 3D concrete printing needs to be controlled to be between 13-21 cm. This limitation is determined so that the concrete mixture also has good buildability. The results of the flow table test can be seen in Figure 4.

From the test results presented in Figure 4, it is found that with the addition of the micro-fibers, the flow diameter of the mixture is reduced by an average of 2.8 cm, as in the example of B_C3S2 compared to the B_C3S2_F mixture. The difference in sand particle size does not have a significant effect on the flow diameter. Finally, with the increasing cement to sand ratio, the flow diameter of the mixture decreases. The higher viscosity of the higher cement to sand ratio reduced the workability of the mixture. Less cement content in the mixture was still possible to obtain a cohesive mixture. However, the cement to sand ratio lower than one would cause separation of the extruded mixture, and an additional admixture to overcome segregation is needed. All mixtures investigated met the requirement for 3D printing according to Tay et al. [8], which proposed that a feasible flow diameter for 3D concrete printing is between 13-21 cm.

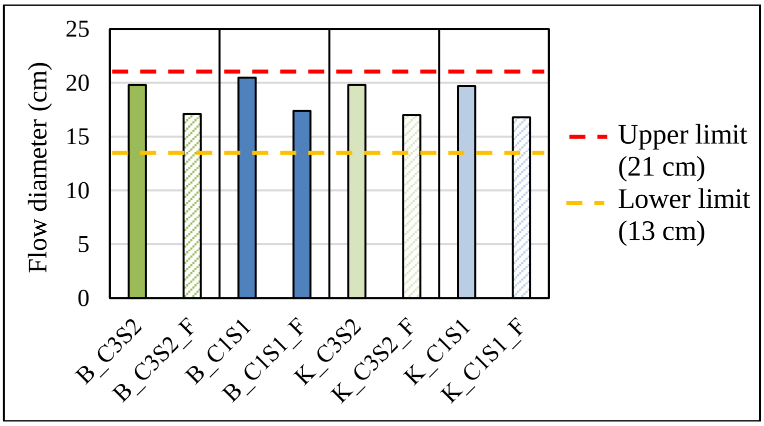


Figure 4. Workability of the mixture.

3.2. Initial setting time

The initial setting time test was carried out using a penetrometer based on ASTM C403 [10]. The test was done on the fresh mortar, and the initial setting time was calculated from the time for the penetrometer to reach 3.45 MPa (500 psi) of pressure for 25.4 mm insertion. The results of the initial setting time are shown in Figure 5. It was found that the addition of micro-fibers accelerated the initial setting time of the concrete. The result was consistent for all mixtures with a 20-30% reduction of the setting time when fiber was added to the mixture.

Furthermore, the smaller maximum sand particle size also had accelerated initial setting time, for example, the faster setting time for the K series compared to the B series. This condition could be due to the higher surface area of the sand particle, hastening the drying of the mortar. All mixtures met the initial setting time requirement for 3D concrete printing of under 90 minutes, according to Kim et al. [11].

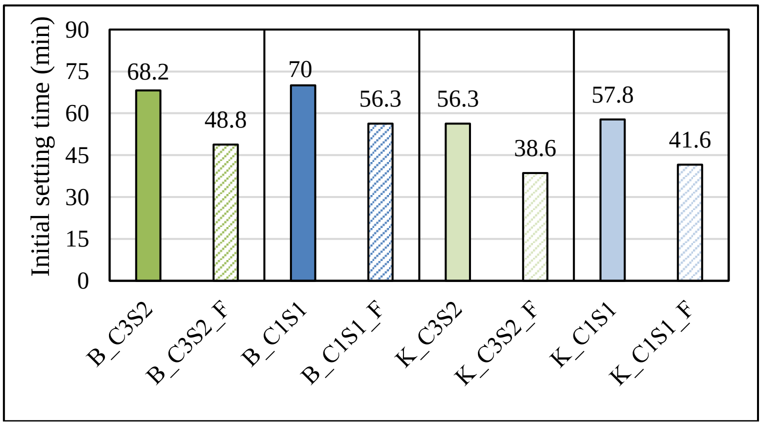


Figure 5. Initial setting time for the mixture.

3.3. Extrudability

For the extrudability test, two mixtures were selected for testing, namely B_C1S1 and B_C1S1_F. The B_C1S1 was chosen due to its higher flow diameter than other mixtures, and the B_C1S1_F to show the influence of fiber in the extrusion process.

This test was carried out with three types of nozzles A, B, and C because the material cannot be extruded using nozzle D due to its small opening. Smaller nozzle opening required higher mixture workability and needs to be investigated further when fine printing resolution is needed. For the current testing, a larger nozzle area seems more suitable for the current mixture. The extruded concretes are shown in Figure 6 to Figure 11.

The tests conducted found that the mixture without synthetic micro-fiber has more cracks than the mixture that used synthetic micro-fiber. The cracks occurrence can be seen in Figure 6 (mixture B_C1S1 without synthetic micro-fiber using nozzle A). It can be seen from the figure that there are quite a lot of cracks, while the extruded concrete was better in Figure 9 (mixture B_C1S1_F with additional synthetic micro-fiber using nozzle A). The extrusion process was not very smooth due to the manual setup. However, the process aims to examine the extrusion process, and it is equivalents to the real setup when using machine-controlled movement.

Figure 6. Mixture B_C1S1 printed with nozzle A.

Figure 7. Mixture B_C1S1 printed with nozzle B.

Figure 8. Mixture B_C1S1 printed with nozzle C.

Figure 9. Mixture B_C1S1_F printed with nozzle A.

Figure 10. Mixture B_C1S1_F printed with nozzle B.

Figure 11. Mixture B_C1S1_F printed with nozzle C.

In the extrusion results, the average layer thickness was measured for every three layers. Table 2 shows the average thickness of the extruded layer. The measured thickness in hardened concrete showed the buildability of the concrete. However, the current setup cannot be used for the buildability examination due to the un-even extrusion process and difficulty in controlling the extrusion speed. The factors that may affect the extrusion process are the dimension of the nozzle, the speed of the horizontal motion in relation to the extrusion speed, the distance between the nozzle and the printing bed, and the constancy of the pressure applied on the concrete extruder.

Table 2. The average thickness of 3 layers for each mixture.

Code	Nozzle type	The average thickness of 3 layers
B_C1S1	Nozzle A	1.5 cm
	Nozzle B	1.5 cm
	Nozzle C	1.6 cm
B_C1S1_F	Nozzle A	1.4 cm
	Nozzle B	1.4 cm
	Nozzle C	1.5 cm

3.4. Compressive strength

The results of the concrete compressive strength test for the cube specimens can be seen in Figure 12. Three replications were done for each testing date. Higher compressive strength was observed for the higher cement content and smaller maximum particle size in the mixture. Meanwhile, using synthetic micro-fiber in the mixture reduced the compressive strength by an average of 5.19% compared to one without micro-fiber. The addition of fiber tends to reduce the workability and increase the inclusion of air voids during the mixing process.

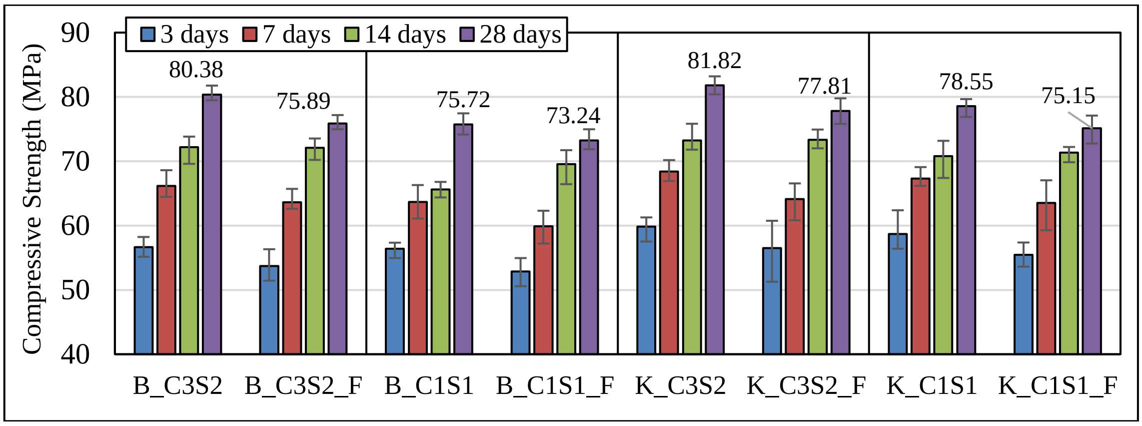


Figure 12. The compressive strength of the cube specimens.

Figure 13 shows the compressive strength of the extruded sample compared to the cube specimens. The results showed a very significant reduction of strength for the extruded samples. Strength reduction for the B_C1S1 mixture with the compressive strength of 75.52 MPa was reduced to 31.13 MPa, 20.90 MPa, and 17.17 MPa when extruded using nozzle A, nozzle B, and nozzle C, respectively.

The strength reduction was less for the B_C1S1_F fiber mixture, showing a reduction of compressive strength of 73.24 MPa to 44.49 MPa, 12.23 MPa, and 18.69 MPa for the nozzle A, nozzle B, and nozzle C, respectively. Without compaction, the extrusion process would affect the hardened concrete drastically. The voids in the fresh mixture were extruded with the concrete and hardened as air void in the mixture.

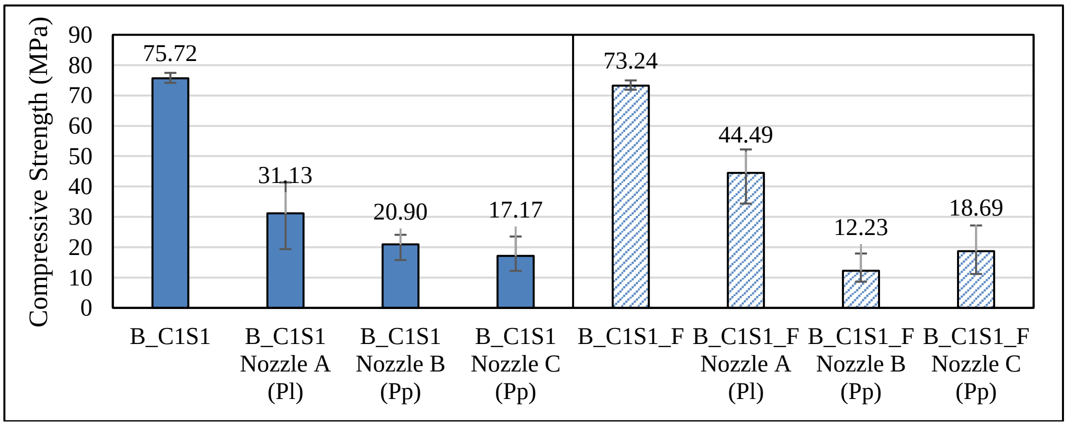


Figure 13. Compressive strength of extruded specimen compared to the cube specimen.

The extruded concrete specimen loaded with a parallel (pl) compressive load to the specimen's cross-section has greater compressive strength than specimens with a perpendicular (pp) compressive load. The difference in strength showed that the extruded concrete has an orthotropic property depending on the extrusion direction and loaded surface. The parallel specimen was shown to have higher compressive strength when tested. The load applied perpendicularly affects the strength of the bond between the specimen layers, in contrast to the parallel load where the bond strength between layers is not reduced but improved.

4. Conclusion

- The mixture with a higher cement-to-sand ratio has greater compressive strength and a smaller flow diameter because of the fresh mixture's higher compaction and high viscosity. The increase in the cement-to-sand ratio also causes the concrete to have a slightly faster initial setting time.

- The use of sand with a smaller particle size could result in a faster initial setting time. The difference in sand particle size did not affect the compressive strength and workability of the mixture investigated in this study.
- The addition of synthetic micro-fibers accelerated the initial setting time, reduced the workability of the mixture, and decreased the compressive strength of concrete by 5.19% compared to the mixture without the micro-fibers. However, micro-fiber can be beneficial as it reduces microcracks that occur in the extruded concrete.
- The extruded concrete showed to have a significant strength reduction compared to the compacted cube specimen. Without compaction, the concrete could trap many air voids and was not freed in the casting process.
- There is an effect in the load direction on the compressive strength of the extruded concrete. The 3D printed concrete loaded parallel or perpendicular to its printing direction could have different compressive strengths. The bond between each layer, extrusion pressure from the subsequent layer, and the setting time of the mixture would play a significant role in controlling the compressive strength.
- All mixtures selected met the requirement in setting time and workability for the 3D concrete printing process. The B_C1S1_F mixture achieved the desired properties for the extrusion process. However, depending on the extrusion machine setup and nozzle size, the mixture needs to be readjusted to have the required workability.

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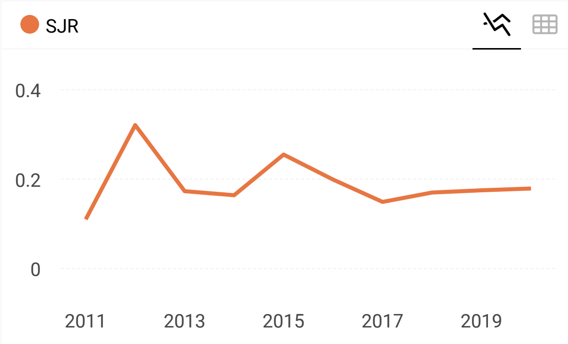

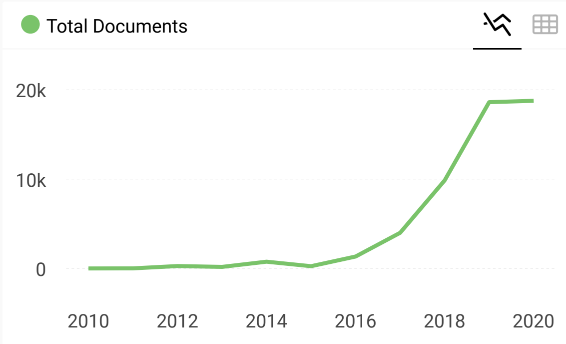

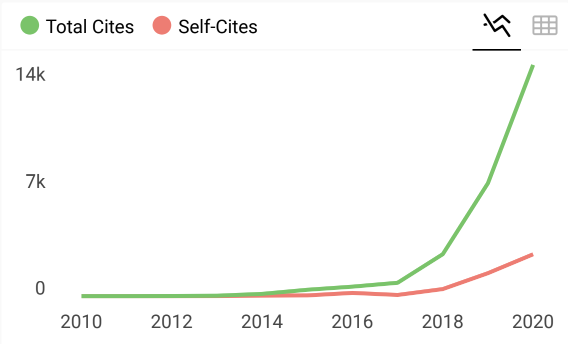

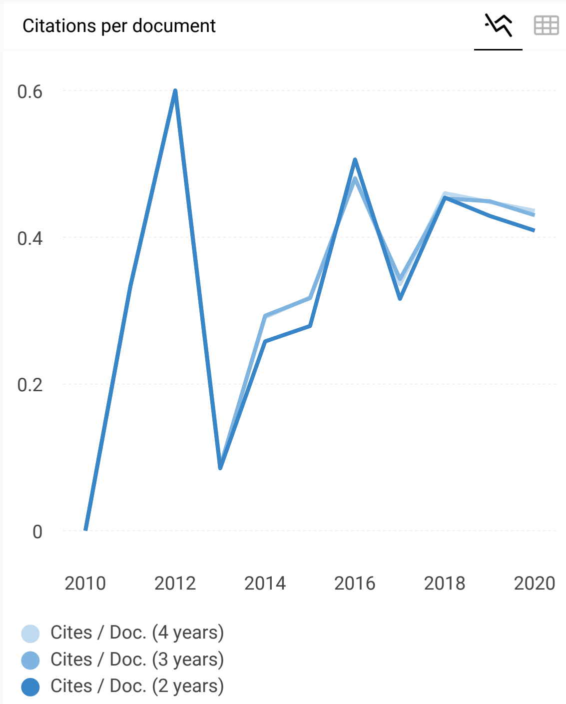

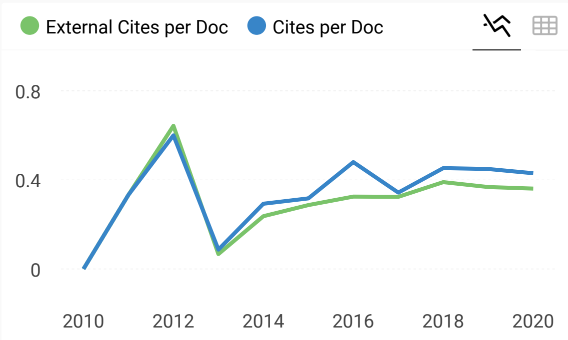

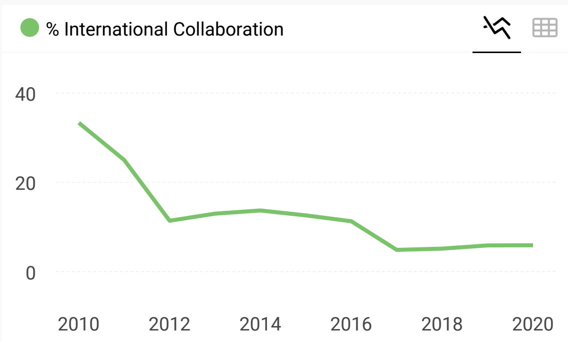

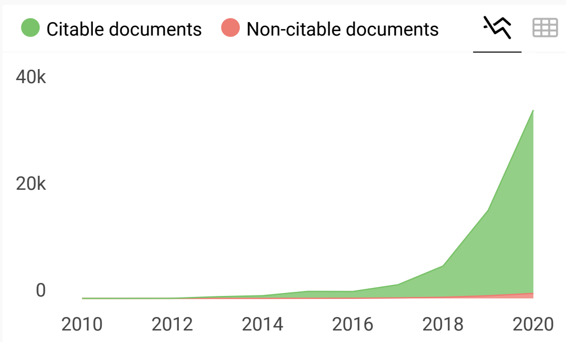

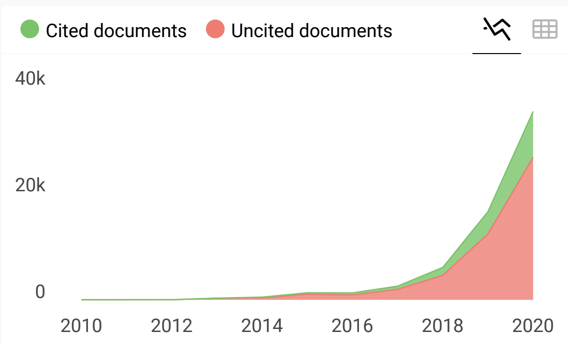

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