Organized by:
University of Zagreb
Faculty of Textile Technology

ITC &DC

BOOK OF PROCEEDINGS

of the 10th International Textile, Clothing & Design Conference

Magic World of Textiles

Dubrovnik, CROATIA

October 2nd to October 5th, 2022

10th INTERNATIONAL TEXTILE CLOTHING & DESIGN CONFERENCE
October 2nd to October 5th, 2022, Dubrovnik, CROATIA

Magic World of Textiles

BOOK OF PROCEEDINGS

Organized by:
University of Zagreb
Faculty of Textile Technology
Zagreb, CROATIA

Under the Auspices of:

MINISTRY OF SCIENCE, EDUCATION AND SPORT
Zagreb, Croatia

UNIVERSITY OF ZAGREB
Zagreb, Croatia

CROATIAN ACADEMY OF ENGINEERING
Zagreb, Croatia

DANUBE ADRIA ASSOCIATION FOR AUTOMATION & MANUFACTURING
Vienna, Austria

ASSOCIATION OF UNIVERSITIES FOR TEXTILES
Ghent, Belgium

INTERNATIONAL FEDERATION OF KNITTING TECHNOLOGISTS
Reutlingen Germany

INTERNATIONAL TECHNICAL COMMITTEE FOR TEXTILE CARE

CROATIAN ASSOCIATION OF TEXTILE ENGINEERS
Zagreb, Croatia

TEXTILE SCIENCE RESEARCH CENTER
Zagreb, Croatia

THE FIBER SOCIETY
Advancing Scientific Knowledge Pertaining to Fibers and Fibrous Materials
THE FIBER SOCIETY

Book of Proceedings (International textile, clothing & design conference)

Book proc. (Int. text. cloth. des. conf.)

ISSN 1847-7275

Publisher: University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

Editor in Chief: Zvonko DRAGČEVIĆ

Editors: Anica HURSA ŠAJATOVIĆ & Edita VUJASINOVIĆ

Editorial Board: Tanja PUŠIĆ, Bosiljka ŠARAVANJA, Ivana ŠPELIĆ, Edita VUJASINOVIĆ, Marijana PAVUNC SAMARŽIJA, Zorana KOVAČEVIĆ

Logo of ITC&DC created by: Ratko JANJIĆ - Jobo

Cover & WWW site of ITC&DC designed by: Natali KRMPOTIĆ KOLIĆ

Graphic design: Sunčica BJEDOV

Editor's Note

All the papers presented in this publication have been reviewed and approved by International Review Committee. However, the editor and the ITC&DC 2022 organiser are not responsible for the contents and the opinions expressed in the papers presented. All the rights belong to the authors, meaning further publication conditions should be agreed upon with the authors in question.
After this Book of Proceedings ITC&DC 2022 has been published, the authors and other persons/institutions wishing to publish reference or in some other manner use the papers published here, are kindly requested to explicitly identify prior publication in the Book of Proceedings of the ITC&DC 2022, including the ISSN number above and page numbers concerned.
The proceedings of the International Textile Clothing and Design Conference have been indexed in the Conference Proceedings Citation Index- Science (CPCI-S), while a selection of the papers from the 10th ITC&DC 2022 will be published in the following publications: International Journal of Clothing Science and Technology (ISSN 0955-6222), Kemija u industriji (ISSN 0022-9830), Tekstil (ISSN 0492-5882) and TEKSTILEC (ISSN 0351-3386).

Publisher contact address:

Organising Committee ITC&DC 2022
University of Zagreb
Faculty of Textile Technology
Prilaz baruna Filipovića 28a
HR-10 000 Zagreb, Croatia
Phone/fax: ++ 385 1 37 12 535
E-mail: itcdc@ttf.hr

International Scientific/Programme Committee of the 10th ITC&DC 2022

Zvonko DRAGČEVIĆ, University of Zagreb, Zagreb, Croatia (President)

Anica HURSA ŠAJATOVIĆ, University of Zagreb, Zagreb, Croatia (Vice-President)

Dominique C. ADOLPHE, Université Française d'Égypte, Cairo, Egypt
Azam ALI, University of Otago, Dunedin, New Zealand
Antonela CURTEZA, University of Iassy, Iassy, Romania
Chuansi GAO, Lund University, Lund, Sweeden
Jelka GERŠAK, University of Maribor, Maribor, Slovenia
Jaime C. GRUNLAN, Texas A&M University, Texas, United States of America
Hüseyin KADOGLU, Ege University, Izmir, Turkey
Branko KATALINIĆ, Vienna University of Technology, Vienna, Austria
Thomas LUXBACHER, Anton Paar, Austria
Malgorzata MATUSIAK, Lodz University of Technology, Lodz, Poland
Rimvydas MILAŠIUS, Kaunas University of Technology, Kaunas, Lithuania
Jiri MILITKY, Technical University of Liberec, Liberec, Czech Republic
Fernando Batista NUNES FERREIRA, University of Minho, Guimaraes, Portugal
Klaus OPWIS, German Textile Research Centre North-West, Krefeld, Germany
Elizabeth RAMOS KALMAR, University of Los Andes, Bogota, Colombia
Ivo SOLJAČIĆ, University of Zagreb, Zagreb, Croatia
Norma STARSZAKOWNA, The London Institute, London, Great Britain
George STYLIOS, Herriot-Watt University, Galashiels, Great Britain
Xiaoming TAO, Hong Kong Polytechnic University, Hong Kong, China
Anna UJHELYIOVÁ, Slovak Technical University, Bratislava, Slovakia
Savvas G. VASSILIADIS, Technological Education Institute of Piraeus, Athenes, Greece
Malgorzata ZIMNIEWSKA, Institute of Natural Fibres & Medicinal Plants, Poznan, Poland

Organizing Committee of the 10th ITC&DC 2022 (ITC&DC Team)

Tanja PUŠIĆ, Edita VUJASINOVIĆ, Bosiljka ŠARAVANJA, Ivana ŠPELIĆ, Zorana KOVAČEVIĆ, Marijana PAVUNC SAMARŽIJA, Marin ŠPERANDA, Katia GRGIĆ, Željka PAVLOVIĆ

International Review Committee of the 10th ITC&DC 2022

Azam ALI (NZ), Aleksandra ANIĆ VUČINIĆ (HR), Sandra BISCHOF (HR), Mario CETINA (HR), Edit CSANÁK (HU), Antonela CURTEZA (RO), Virginija DAUKANTIENĖ (LT), Tihana DEKANIĆ (HR), Zvonko DRAGČEVIĆ (HR), Krešimir DRAGČEVIĆ (HR), Sanja ERCEGOVIĆ RAŽIĆ (HR), Sabina FIJAN (SI), Sandra FLINČEC GRGAC (HR), Petra FORTE TAVČER (SI), Petra FRANITZA (DE), Jelka GERŠAK (SI), Jaime C. GRUNLAN (USA), Renata HRŽENJAK (HR), Anica HURSA ŠAJATOVIĆ (HR), Igor JORDANOV (MK), Romana KOREZ VIDE (SI), Sonja KOŠČAK KOLIN (HR), Zorana KOVAČEVIĆ (HR), Karlo LELAS (HR), Thomas LUXBACHER (AT), Rossane MAILDE SANTOS (BR), Jadranko MATUŠKO (HR), Daiva MIKUČIONIENĖ (LT), Rimvydas MILAŠIUS (LT), Branko NERAL (SI), Klaus OPWIS (DE), Marijana PAVUNC SAMARŽIJA (HR), Željko PENAVA (HR), Slavenka PETRAK (HR),Tanja PUŠIĆ (HR), Elizabeth RAMOS KALMAR (CO), Dubravko ROGALE (HR), Tomislav ROLICH (HR), Katarina Nina SIMNOČIČ (HR) Zenun SKENDERI (HR), Ivo SOLJAČIĆ (HR), Maja STRACENSKI KALAUZ (HR), Bosiljka ŠARAVANJA (HR), Ivana ŠPELIĆ (HR), Anita TARBUK (HR), Josip VINČIĆ (IT), Branka VOJNOVIĆ (HR), Julija VOLMAJER VALH (SI), Bojana VONČINA (SI), Zlatko VRLJIČAK (HR), Edita VUJASINOVIĆ (HR), Xungai WANG (AU)

PREFACE

Dear colleagues, dear friends!

The Faculty of Textile Technology, University of Zagreb, has organised the 10th International Textile, Clothing and Design Conference – **Magic World of Textiles,** making this conference a traditional one.

Our big ITC&DC family has grown through nine ITC&DC conferences organised up to now, and it includes more than 3021 authors with 1336 papers from 38 countries of Europe and all over the world. As every decent family, we have found, thanks to the hospitality of the Centre for Advanced Academic Studies (CAAS), our home here in Dubrovnik. Beside this, there are a lot of other reasons why the ITC&DC is organised in Dubrovnik. Historically speaking, at the time of the Dubrovnik Republic (from the early Middle Ages to the time of the Napoleonic Wars) the ships of the Republic sailed world-wide, and Dubrovnik even had its colonies (like Goya in India). The part of the town called Pile, where our Conference is held, used to be the centre of textiles in the Dubrovnik Republic, while the peasants in the nearby Konavosko polje reared silkworms and produced silk until the mid-nineteenth century. Dubrovnik is also a city of exceptional cultural and historical monuments and is included in the UNESCO World Heritage List. It is also a city with a millennium (or almost two millennia) history, where everybody can find his/her true self.

I would like to express my warm welcome to all of you in Dubrovnik! I am personally grateful to all the colleagues who attended previous ITC&DC for coming again to the beautiful town of Dubrovnik. However, I am sincerely happy for those who are here in Dubrovnik and Croatia for the first time.

Of all the papers received this year, the members of the International Reviewer Committee have accepted 89 papers for the 10th ITC&DC and 76 of them are published in this Book of Proceedings. I would like to express my sincerest thanks to all the participants for their valuable contribution and readiness to spend a part of their time in Dubrovnik, making the picture of the Magic World of Textiles more valuable and more real.

My special thanks go to the Croatian Ministry of Science, as well as to the international scientific associations that have accepted to be the patrons of the conference, proving it to be necessary, justified and useful. My gratitude also goes to all the individuals and institutions that have helped us organise the 10th ITC&DC.

Zvonko DRAGČEVIČ

Final report for ITC&DC Conferences – Magic World of Textiles

1st ITC&DC 2002

Date & Place	October 6-9th 2002, Dubrovnik, Croatia
Under the Auspices	DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; The Textile Institute, Manchester, United Kingdom; The International Textile Academy New Delhi, India; University of Zagreb, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), A.P. Cavaco (PT), Z. Dragčević (HR), J. Geršak (SI), B. C. Goswami (US), P. K. Hari (IN), B. Katalinić (AT), D. Katović (HR); P. Kiekens (BE), I. Krucinska (PL), J. Kurz (DE); A. Marcincin (SK), J. Militky (CZ), P. Offermann (DE), K. Slater (CA); Z. Sukang (CN), N. Starszakowna (GB), G. Stylios (GB), C. Q. Yang (US).
Plenary lecture	Branko KATALINIĆ: Technical Product as Materilisation of Engineers Idea and Design Strategy of Nature
Publication	Book of Proceedings of the International Textile, Clothing & Design Conference, ISBN 953-96408-8-1
Editor	Zvonko Dragčević
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	239 / 129
Number of Countries Participants came from	26
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S), World Textile Abstracts, Textile Technology Digest, Textile Global/Net, Chemical Abstracts
Selected Papers published in Journals after Conference	International Journal of Clothing Science and Technology, **15** (2003) 3/4, (ISSN 0955-6222)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, D. Grundler, A. Hursa, N. Krmpotić, T. Rolich, D. Rogale, E. Vujasinović

2nd ITC&DC 2004

Date & Place	October 3-6th 2004, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Ministry of Economy, Labour and Entrepreneurship, Zagreb, Croatia; Croatian Chamber of Economy, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; The Textile Institute, Manchester, United Kingdom; The International Textile Academy New Delhi, India; Croatian Academy of Engineering, Zagreb, Croatia; Croatian Society of Chemical Engineers, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), M. Akalin (TR), M. Duarte de Araujo (PT), S. K. Batra (US), X. Ding (CN), Z. Dragčević (HR), J. Geršak (SI), B. C. Goswami (US), P. K. Hari (IN), H. Harms (AT), B. Katalinić (AT), I. Krucinska (PL), J. Kurz (DE); A. Marcincin (SK), H.J. Mencer (HR), J. Militky (CZ), D. Rogale (HR), E. Schellmeyer (DE), N. Starszakowna (GB), G. Stylios (GB), T. Takagishi (JP), C. Q. Yang (US).

Plenary lecture	George K. STYLIOS: New Measurement Technologies for Textiles and Clothing
Publication	Book of Proceedings of the 2nd International Textile, Clothing & Design Conference, ISBN 953-7105-05-9
Editor	Zvonko Dragčević
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
ISBN	953-7105-05-9
Authors / Papers	352 / 180
Number of Countries Participants came from	29
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S), World Textile Abstracts, Textile Technology Digest, Textile Global/Net, Chemical Abstracts
Selected Papers published in Journals after Conference	International Journal of Clothing Science and Technology, **17** (2005) 3/4, (ISSN -955-6222)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, A. Hursa, N. Krmpotić, B. Mauser, I. Petrunić, T. Rolich, E. Vujasinović

3rd ITC&DC 2006

Date & Place	October 8-11th 2006, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Ministry of Economy, Labour and Entrepreneurship, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; The Textile Institute, Manchester, United Kingdom; The International Textile Academy New Delhi, India; American Association of Textile Chemists and Colorists, Research Triangle Park, United States of America; Croatian Society of Chemical Engineers, Zagreb, Croatia; International Federation of Knitting Technologists, Reutlingen, Germany; Croatian Chamber of Economy, Zagreb, Croatia; INA Oil Industry, Zagreb, Croatia; City of Dubrovnik, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), M. Akalin (TR), M. Duarte de Araujo (PT), S. K. Batra (US), K. Dimitrovski (SI), Z. Dragčević (HR), J. Geršak (SI), B. C. Goswami (US), P. K. Hari (IN), A. R. Horrocks (GB), B. Katalinić (AT), I. Krucinska (PL), S. Kukle (LV), A. Marcincin (SK), H. J. Mencer (HR), J. Militky (CZ), R. Postle (AU), D. Rogale (HR), E. Schollmeyer (DE), H. Shosenji (JP), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), R. Wardman (GB), C. Q. Yang (US).
Plenary lecture	Eckhard SCHOLLMEYER: Nanotechnology for Functionalization of Textile Materials
Publication	Book of Proceedings of the 3rd International Textile, Clothing & Design Conference, ISBN 953-7105-12-1
Editor	Zvonko Dragčević
Publisher	University of Zagreb, Faculty of Textile Technology Zagreb, Croatia
ISBN	953-7105-12-1
Authors / Papers	414 / 183
Number of Countries Participants came from	31

Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S), World Textile Abstracts, Textile Technology Digest, Textile Global/Net, Chemical Abstracts
Selected Papers published in Journals after Conference	International Journal of Clothing Science and Technology, **19** (2007) 3/4, (ISSN 0955-6222), Kemija u industriji, **56** (2007) 11, (ISSN 0022-9830), Tekstil **56** (2007) 2, (ISSN 0492-5882)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, M. Bobovčan, S. Bogović, I. Geratović, A. Hursa, Đ. Jandrić, M. Martek, K. Matušić, B. Mauser, I. Petrunić, E. Vujasinović

4th ITC&DC 2008

Date & Place	October 5-8th 2008, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Chamber of Economy, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; The Textile Institute, Manchester, United Kingdom; The International Textile Academy New Delhi, India; Society of Dyers and Colourists, Bradford, United Kingdom; Croatian Society of Chemical Engineers, Zagreb, Croatia; INA Oil Industry, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), M. Akalin (TR), M. Duarte de Araujo (PT), A. Curteza (RO), K. Dimitrovski (SI), Z. Dragčević (HR), J. Geršak (SI), B. Katalinić (AT), I. Krucinska (PL), S. Kukle (LV), A.V. Kulichenko (RU), A. Marcincin (SK), H. Mattila (FI), J. Militky (CZ), R. Postle (AU), H. Rödel (DE), E. Schollmeyer (DE), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), D. Ujević (HR), L. Wadsworth (US), C. Q. Yang (US).
Plenary lecture	Charles Q. YANG: New Development in Functional Finishing and Cotton Textiles
Publication	Book of Proceedings of the 4th International Textile, Clothing & Design Conference, ISBN 978-953-7105-26-6
Editor	Zvonko Dragčević
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
ISBN	978-953-7105-26-6
Authors / Papers	438 / 200
Number of Countries Participants came from	34
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S), World Textile Abstracts, Textile Technology Digest, Textile Global/Net, Chemical Abstracts
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, S. Bogović, A. Hursa, B. Mauser, M. Runkas, N.K. Simončić, E. Vujasinović

5th ITC&DC 2010

Date & Place	October 3-6th 2010, Dubrovnik, Croatia
Under the Auspices	President of the Republic of Croatia Prof. Ivo Josipović, Ph.D.; Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Chamber of Economy, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; Croatian Society

	of Chemical Engineers, Zagreb, Croatia; American Association of Textile Chemists and Colorists, Research Triangle Park, United States of America; International Federation of Knitting Technologists, Reutlingen, Germany; ESCORENA Poznan, Poland; CARNet, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), M. Duarte de Araujo (PT), A. Bjeliš (HR), H.J. Buschmann (DE), A. Curteza (RO), K. Dimitrovski (SI), Z. Dragčević (HR), J. Geršak (SI), R. Horrocks (GB), H. Kadoglu (TR), B. Katalinić (AT), R.M. Kozlowski (PL), S. Kukle (LV), A.V. Kulichenko (RU), R. Laing (NZ), A. Marcincin (SK), H. Mattila (FI), J. Militky (CZ), R. Postle (AU), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), D. Ujević (HR), S.G. Vassiliadis (GR), X. Wang (AU), C. Q. Yang (US).
Plenary lecture	Dubravko ROGALE: Research and Development of Article of Clothing with Adaptive Microklimatic States
Publication	Book of Proceedings of the 5th International Textile, Clothing & Design Conference, ISSN 1847-7275 [Book proc. (Int. text. cloth. des. conf.)]
Editors	Zvonko Dragčević, Anica Hursa Šajatović, Edita Vujasinović
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	423 / 168
Number of Countries Participants came from	36
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S)
Selected Papers published in Journals after Conference	Tekstil, **59** (2010) 12, (ISSN 0492-5882)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, A. Hursa Šajatović, Z. Kovačević, B. Mauser, B. Šaravanja, T. Tisaj, S. Vlatković, E. Vujasinović

6th ITC&DC 2012

Date & Place	October 7-10th 2012, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; Croatian Chamber of Economy, Zagreb, Croatia; Ministry of Entrepreneurship and Trade, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; American Association of Textile Chemists and Colorists, Research Triangle Park, United States of America; ESCORENA Poznan, Poland; International Federation of Knitting Technologists, Reutlingen, Germany; Croatian Society of Chemical Engineers, Zagreb, Croatia; Croatian Association of Textile Engineers, Zagreb, Croatia; International Technical Committee for Textile Care; Croatian Zeolite Association, Zagreb, Croatia; CARNet, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), M. Duarte de Araujo (PT), M. Beeh (DE), A. Bjeliš (HR), H.J. Buschmann (DE), A. Curteza (RO), K. Dimitrovski (SI), Z. Dragčević (HR), J. Geršak (SI), M. Heuberger (CH), H. Kadoglu (TR), B. Katalinić (AT), R.M. Kozlowski (PL), S. Kukle (LV), A.V. Kulichenko (RU), R. Laing (NZ), H. Mattila (FI), R. Milašius (LT), J. Militky (CZ), R. Postle (AU), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), D. Ujević (HR), A. Ujhelyiova (SK), S.G. Vassiliadis (GR), C. Q. Yang (US).
Plenary lecture	Ron POSTLE: Mechanics and Physics of Soft Matter: Knitted Fabrics

Publication	Book of Proceedings of the 6th International Textile, Clothing & Design Conference, ISSN 1847-7275 [Book proc. (Int. text. cloth. des. conf.)]
Editors	Zvonko Dragčević, Anica Hursa Šajatović, Edita Vujasinović
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	275 / 125
Number of Countries Participants came from	34
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S)
Selected Papers published in Journals after Conference	Tekstil, **61** (2012) 7-12, (ISSN 0492-5882)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, M. Bobovčan Marcelić, A. Hursa Šajatović, Z. Kovačević, I. Matijević, B. Mauser, B. Šaravanja, E. Vujasinović

7th ITC&DC 2014

Date & Place	October 5-8th 2014, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; Ministry of Economy, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; American Association of Textile Chemists and Colorists, Research Triangle Park, United States of America; ESCORENA Poznan, Poland; International Federation of Knitting Technologists, Reutlingen, Germany; Croatian Society of Chemical Engineers, Zagreb, Croatia; Croatian Association of Textile Engineers, Zagreb, Croatia; CARNet, Zagreb, Croatia
Scientific Committee	I. Soljačić (HR) – president; D. C. Adolphe (FR), S. Bischof (HR), H.J. Buschmann (DE), A. Curteza (RO), K. Dimitrovski (SI), Z. Dragčević (HR), F.B.N. Ferreira (PT), J. Geršak (SI), J.W.S. Hearle (UK), H. Kadoglu (TR), B. Katalinić (AT), R.M. Kozlowski (PL), S. Kukle (LV), A.V. Kulichenko (RU), R. Laing (NZ), H. Mattila (FI), R. Milašius (LT), J. Militky (CZ), M. Neznakomova (BG), P. Al Pscheid (ID), R. Postle (AU), A. Ujhelyiova (SK), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), S.G. Vassiliadis (GR), C. Q. Yang (US).
Plenary lecture	John W.S. HEARLE: From Calculators to 21st Century Computing: Successes and Opportunities in Digital Technology for the Textiles
Publication	Book of Proceedings of the 7th International Textile, Clothing & Design Conference, ISSN 1847-7275 [Book proc. (Int. text. cloth. des. conf.)]
Editors	Zvonko Dragčević, Anica Hursa Šajatović, Edita Vujasinović
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	265 / 116
Number of Countries Participants came from	29
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S)
Selected Papers published in Journals after Conference	Tekstil, **63** (2014) 11-12, (ISSN 0492-5882)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, A. Hursa Šajatović, B. Mauser, M. Pavunc, B. Šaravanja, T. Šimunić, I. Špelić, E. Vujasinović

8th ITC&DC 2016

Date & Place	October 2-5th 2016, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; Croatian Chamber of Economy, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; American Association of Textile Chemists and Colorists, Research Triangle Park, United States of America; ESCORENA Poznan, Poland; International Federation of Knitting Technologists, Reutlingen, Germany; Croatian Society of Chemical Engineers, Zagreb, Croatia; Croatian Association of Textile Engineers, Zagreb, Croatia; CARNet, Zagreb, Croatia; International Technical Committee for Textile Care; Textile Science Research Center, Zagreb, Croatia
Scientific Committee	S. Bischof (HR) – president; D. C. Adolphe (FR), G.J. Brinks (NE), A. Curteza (RO), K. Dimitrovski (SI), Z. Dragčević (HR), J. Geršak (SI), J.W.S. Hearle (UK), H. Kadoglu (TR), B. Katalinić (AT), R.M. Kozlowski (PL), S. Kukle (LV), A.V. Kulichenko (RU), T. Luxbacher (AT), H. Mattila (FI), R. Milašius (LT), J. Militky (CZ), K. Opwis (DE), R. Postle (AU), I. Soljačić (HR), N. Starszakowna (GB), G. Stylios (GB), X. Tao (CN), A. Ujhelyiova (SK), C. Q. Yang (US).
Plenary lecture	Dominique C. ADOLPHE: The Electro-Spinning Devices the Opened Door to the Nano Dimension
Publication	Book of Proceedings of the 8th International Textile, Clothing & Design Conference, ISSN 1847-7275 [Book proc. (Int. text. cloth. des. conf.)]
Editors	Zvonko Dragčević, Anica Hursa Šajatović, Edita Vujasinović
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	208 / 81
Number of Countries Participants came from	31
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S)
Selected Papers published in Journals after Conference	Tekstil, **65** (2016) 9-10, (ISSN 0492-5882)
Organising Committee	Z. Dragčević – president, N. Vuljanić – vice president, A. Hursa Šajatović, D. Jokić, B. Mauser, M. Pavunc Samaržija, T. Pušić, B. Šaravanja, I. Špelić, M. Šperanda, E. Vujasinović

9th ITC&DC 2018

Date & Place	October 7-10th 2018, Dubrovnik, Croatia
Under the Auspices	Ministry of Science, Education and Sport, Zagreb, Croatia; University of Zagreb, Zagreb, Croatia; Croatian Academy of Engineering, Zagreb, Croatia; DAAAM International, Vienna, Austria; AUTEX, Ghent, Belgium; International Federation of Knitting Technologists, Reutlingen, Germany; Croatian Association of Textile Engineers, Zagreb, Croatia; International Technical Committee for Textile Care; Textile Science Research Center, Zagreb, Croatia
Scientific Committee	Zvonko DRAGČEVIĆ (HR) – President; Dominique C. ADOLPHE (FR); Sandra BISCHOF (HR); Antonela CURTEZA (RO); Mizi FAN (UK); Jelka GERŠAK (SI); Jaime C. GRUNLAN (US); Hüseyin KADOGLU (TR); Branko KATALINIĆ (AT); Lieva Van LANGENHOVE (BE); Thomas LUXBACHER (AT); Rimvydas MILAŠIUS (LT); Jiri MILITKY (CZ); Klaus OPWIS (DE); Ivo SOLJAČIĆ (HR); Norma STARSZAKOWNA (UK);

	George STYLIOS (UK); Xiaoming TAO (CN); Anna UJHELYIOVÁ (SK); Savvas G. VASSILIADIS (GR); Malgorzata ZIMNIEWSKA (PL); Charles Q. YANG (US)
Plenary lecture	Marina CRNOJA-COSIC; Berndt KÖLL; Nicole SCHRAM; Birgit SCHNETZLINGER; Roland ARBESLEITNER & Robert MALINOWSKY: ADVANCED TEXTILES – RELEVANCE AND POTENTIALS FOR CONSUMERS & INDUSTRY
Publication	Book of Proceedings of the 9th International Textile, Clothing & Design Conference, ISSN 1847-7275 [Book proc. (Int. text. cloth. des. conf.)]
Editors	Zvonko Dragčević, Anica Hursa Šajatović, Edita Vujasinović
Publisher	University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
Authors / Papers	163 / 59
Number of Countries Participants came from	22
Refered /Indexed in	Conference Proceedings Citation Index – Science (CPCI-S)
Selected Papers published in Journals after Conference	Tekstil, **67** (2018) 11-12, (ISSN 0492-5882)
Organising Committee	E. Vujasinović (President), A. Hursa Šajatović (Vice-president), F. Benjak, B. Mauser, T. Kaurin, M. Pavunc Samaržija, T. Pušić, B. Šaravanja, I. Špelić, M. Šperanda, T. Vukelić

CONTENTS

SECTION D: ANALYSIS, TESTING AND QUALITY CONTROL 193

PLENARY LECTURE

FUTURE TEXTILES - BACK TO THE PAST

Sandra Bischof

Abstract: *To be able to bring new knowledge and make contribution at the global stage of frenetic technology development it is crucial to follow new strategies and if possible, to be at the forefront of the proposed activities. In the world of technology development textile holds small part in the eyes of the non-experts, but the ones who dedicated their carrier to this narrow area knows better! It is not just a simple phrase that textile is everywhere – this paper will present state of the art in the world of textiles, so as some of the past and future initiatives. All the major strategies have the same goal – to produce better, more advanced, more desirable product which at the same time pollutes our Globe the least! Past initiatives, with the accent on textile finishing, will be presented and their path will be followed until the newest ones. The key issue is to disclose how big is the real difference between future and past initiatives and to find our own place in proposed models of future circular, sustainable and/or biodegradable textiles within this, maybe small, but very innovative textile sector.*
Keywords: *circular textiles, advanced materials & technologies, high performance textile finishing, traditional agents, sustainable economy, bioeconomy*

1. Introduction

The main question posed at the beginning is what is the actual size of the EU textile market? The newest data presented by European Technology Platform for the Future of Textiles and Clothing (ETP FTC) at Annual Conference in April 2022 revealed that 1.3 mil people in EU are employed in textile & leather industry. Those 143.000 companies, mostly SMEs, are generating a turnover of 147 billion EUR [1]. Except those nice figures of size of the profit, there is another side as well – the negative impact of industry on resources, environment and consequently on climate changes.

Global consumption of materials such as fossil fuels, metals, minerals and biomass is predicted to double in the next forty years. At the same time, annual waste production will increase by 70% by 2050 [2]. The impact of the textile industry is extremely significant from the point of view of reducing environmental pollution, taking into the consideration that textile industry is among five biggest polluters. The paper presents the most commonly used contaminants that cause pollution, both in general and in the textile industry. Furthermore, solutions for cleaner production are presented, which include the use of environmentally friendly agents, devices and highly efficient processes, so as the maximum utilization of each substance and waste, followed by reuse, recycling, composting, maximum energy recovery and finally disposal is performed in a not harmful to the environment way.

Although textile waste and its environmental damage are not so widely discussed as the adverse effects of plastic packaging or electronics, textiles fall into the fourth category (after food, household and transport) primarily due to the need to reduce the use of primary raw materials and water. It is additionally important to note that textiles are fifth in terms of greenhouse gas emissions [3]. The realization that textiles are one of the key elements of environmental pollution and that each year they represent the majority in municipal waste, causes the need to introduce a circular economy in this sector [4-5].

The goal of the circular economy is to produce longer-lasting products, which can be repaired or easily disassembled and recycled, replacing the linear model of cheap and fast production and disposal. This may sound like a waste collection and recycling plan, but the circular economy model is essentially much more complex. Reorganization, new ways of management, modernization of economic activities are very important in order to enable changes in organizational structures by changing numerous processes. The concept of the circular economy presupposes the success of the company but envisages improvements for the environment and society, and not just for customers and investors.

2. Novel initiatives in the world of textiles

2.1 Textiles & Circular Economy

The relentless depletion of natural resources, and the daily accumulation of waste that pollutes the environment and creates more and more environmental problems, requires a change in the model of waste

management. It is necessary with the current linear economy, to take a step forward and replace it with a sustainable alternative, such as a circular economy. Currently, the focus is still on the largest possible production of cheap products that will quickly end up in landfills and their replacement with new products, which ultimately means more waste and greater environmental pollution. This approach of linear economy is described as: Take! – Make! – Use! - Dispose! (figure 1).

Thus, a linear system consists of the extraction of resources, their use in production, distribution of produced, marketing, the use of products by consumers, and ends with the disposal of waste. Although the system appears to be good and simple, it is actually very limited because it is one-way and unsustainable due to limited resources. It is therefore necessary to move from a linear model to a circular one.

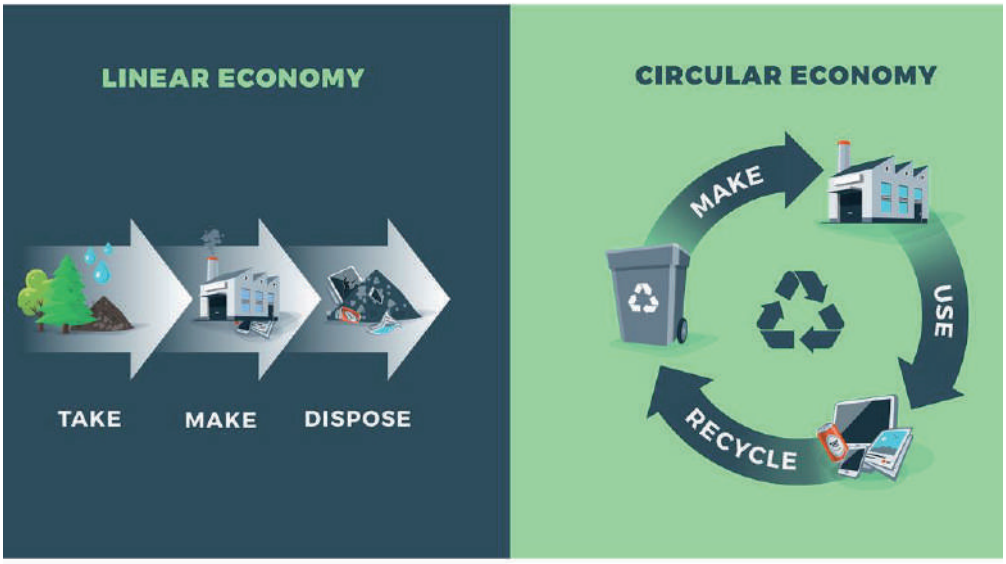


Figure 1: Linear vs Circular Economy [6]

Although Strategy towards Circular Economy [7] has been introduced in 2014, its Action plan has already been revised in 2020 [8]. Additionally, its influence on the market was revealed in EURATEX's document [2]. This Strategy prioritises removing barriers to a large-scale uptake of circular economy in textiles and proposes 12 specific points to coordinate efforts in Europe (figure 2).

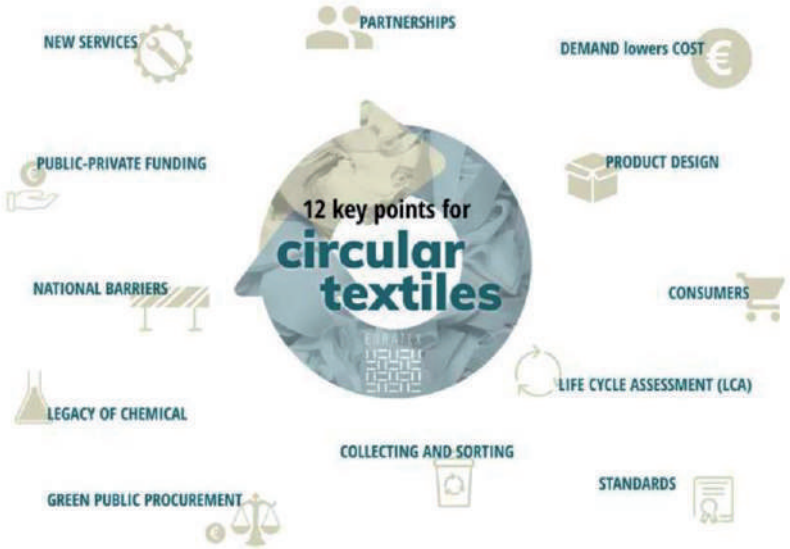


Figure 2: Specific points to enable enforcement of Circular Economy in EU [2]

One of the key issues is that circularity starts with the demand, no matter is it placed by buyer, retailer, public procurer of fashion brand. Therefore, it is of major importance to stimulate a demand for circularity from both sides, buyers, and consumers.

One of the many circular based initiatives organized in recent years is the Circular Fibres Initiative, launched in 2017 as a result of the Global Fashion Summit. It gathers key industrial stakeholders for the purpose of collaboration, so as the innovation towards the new and circular economy. Their idea was developed in the partnership with Ellen MacArthur Foundation and Ideo. Organisation's goal is to deliver benefits to society, environment, so as the businesses, while at the same time making solutions to decrease negative impact of pollution and waste [9]. The prediction of values of negative impact of textile industry by the year 2050 are compared with the values from 2015 within Table 1.

Table 1: Prediction of negative impacts of textile industry by 2050 [9]

Negative impacts of the Textile Industry	2015	2050
Resource consumption: Oil	98 million tonnes	300 million tonnes
Textile industry share of carbon budget	2% CO_2	26% CO_2
Microfibers in the Ocean	Unknown	22 million tonnes added between 2015 and 2050

Data presented in Table 1 are clearly stressing the need to join the efforts of all stakeholders to minimize waste to zero values as proposed by the novel EU Green Deal.

2.2 Textiles & The EU Green Deal

As half of total greenhouse gas emissions and more than 90% of biodiversity loss and water stress come from resource extraction and processing, the European Green Deal [10] launched a concerted strategy for a climate-neutral, resource-efficient and competitive economy. The figure 3 presents various elements of the European Green Deal.

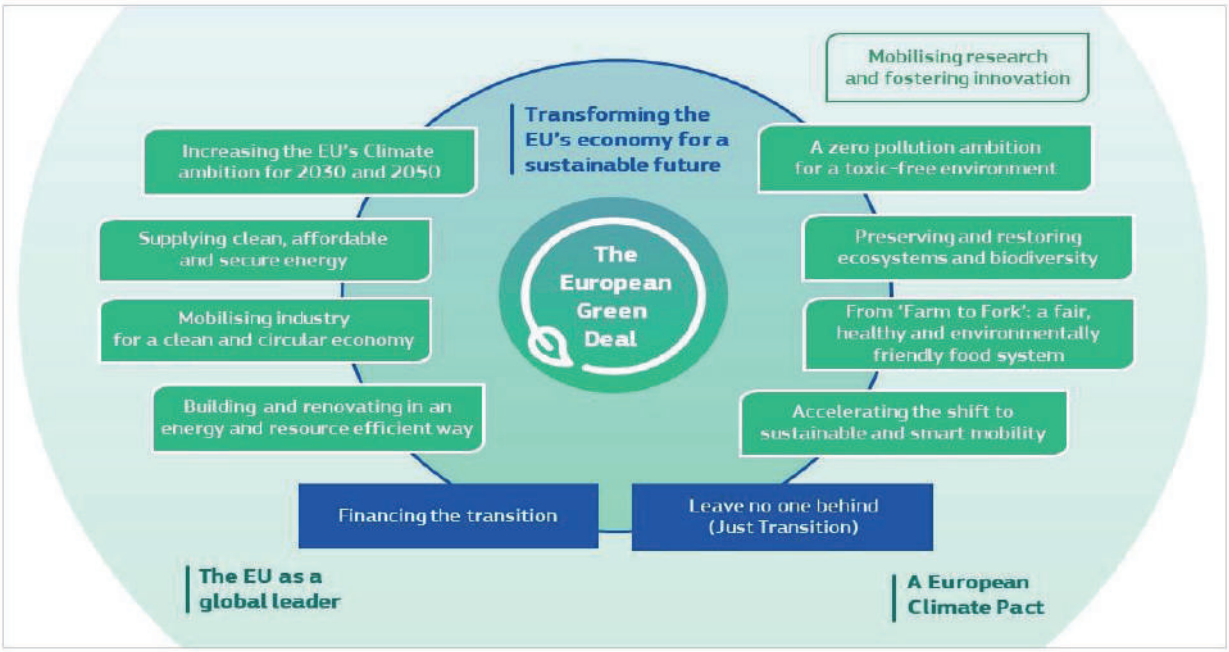


Figure 3: The European Green Deal [10]

The European Green Deal elaborates in detail the items that could eliminate pollution of the environment, water, air and soil by 2050. This plan clearly emphasizes the connection between the circular economy and the environment. Currently, there is a significantly large number of processes in which humans have a negative impact on the environment. Therefore, it was necessary to create a strategy and an action plan in order to ensure a zero level of pollution.

The Action Plan [11] includes the conservation of biodiversity in lakes, rivers and wetlands, the reduction of particularly harmful pollution caused by microplastics and pharmaceuticals, the reduction of pollution caused by excess nutrients, but also the use of pesticides and fertilizers through a field-to-table strategy.

For air quality, it is important to check whether the standards for air quality testing are in accordance with the guidelines of the World Health Organization. It is equally important to support local authorities in ensuring cleaner air for the citizens of the European Union. It is also necessary to increase the prevention of industrial accidents, but also to reduce pollution from large industrial plants. Improved protection of citizens and the environment against hazardous chemicals is extremely important, so the new Chemicals Strategy for Sustainability (toxic-free EU environment) was adapted in 2020 [12]. Additionally, it will encourage the development of safe and sustainable alternatives and the creation of green and sustainable manufacturing capacity in Europe.

Most challenging task for all of us globally will be “A zero waste production”! A question to be posed to ourselves - am I really doing the most I can? And for the teachers, it is crucial to educate each new generation of students to be aware of the problems and to continuously seek the solutions as a part of their future carriers, so as for their every days life! As part of the initiatives of TTF's students of Textile Chemistry, Materials & Ecology programme, within the curriculum *High performance finishing* the students were sparated in two groups dealing with the topic of The Green Deal and their seminars were upgraded to review papers published in Croatian journal Tekstil under the titles: 1. *Impact of The European Green Deal on pollution reduction in textile industry with an emphasis on textile finishing* [13] and 2. *Boosting the efficient use of resources in the textile industry by moving to a circular economy* [14].

3. Traditional versus emerging technologies

When we analyse state of the art of textile finishing it can be noticed that a lot of the changes must occur to fulfil demands of EU strategies and to reshape the linear models of the economy into a circular one. Already the Europe 2020 strategy [15] foresees the positive effects of the circular economy and stresses the priorities of EU development for more efficient resources usage that will enable our economy to become "greener" and more competitive.

Emerging technologies in textile processing focus on:

- Minimum use of resources like water and energy according to Best Available Technologies (BAT) [16]
- Reducing chemical consumption
- No or low pollution load
- Elimination of harmful and toxic chemicals.

3.1 Textile resources

One of the major problems of textile industry is usage of too high quantities of non-renewable raw materials e.g. fossil fuels (coal, oil, gas) for the production of synthetic textiles which still holds approx. 62% of overall textile production.

Therefore, research of finding the new sources of fibers becomes one of the imperatives. Taking into the consideration that 65.5% of renewable energy sources in EU is biomass, it is clear why the newest trends go into the direction of usage of biomass, where agro biomass holds huge percentage (approx. 70%). For the fibre production, lignocellulosic biomass has the highest potential. The most popular cereals in Croatia are corn, barley and wheat and therefore this biomass was used for the extraction of fibers. Equally interesting are fast growing energy cultures such as lat. *Miscanthus giganteus* and lat. *Arundo donax*. Depending on the length and quality of extracted fibres, they can be used either for the conventional fibres or for the production of technical textiles (filters or composites).

Trend that is constantly growing is revitalisation of old cultures production. Most popular are flax and hemp, but other cultures such as lat. *Spartium junceum* L. are exposing equally good fibre quality [17]. All above mentioned cultures can be used for the production of fibres for the clothes, but they are more frequently used for the natural fibre reinforced composites (NFRC). Due to the strong demand to increase the amount of sustainable sources for the production of bio-based and bio-derived products (e.g. textiles, chemicals), biomass started to be a hot topic.

3.2 Textile Agents

There are so many examples of novel environmentally friendly agents, which are used for wide variety of functionalization, starting from the hot topic of antiviral and antibacterial protection all the way to the flame retardant and wellness functionalization.

One of the facts that draw our intention was application of well-known agents of proved efficiency using novel high-performance technologies with reduced environmental footprint, e.g., plasma, microwaves, electrospinning, or Layer-by-Layer (LbL) deposition. Several examples are presented in Table 2.

Table 2: Examples of past vs future trends in textile finishing (papers published by TTF researchers)

Process	Past trends	Future trends
Dyeing	Natural dyestuff	Same dyestuff but modern extraction methods, optimized concentration and mordant types (bio-mordants), so as MW and plasma pretreatments to enhance affinity to natural colorants [18,19]
Antimicrobial functionalization	Ag, Cu, Zn	Same agents at nanosize (e.g. metal or metal oxide nanoparticles) and/or high performance methods: e.g.plasma [20], LbL deposition [21]
Wellness	Immortelle, resemary, lavender	Same agents with new application methods: e.g. encapsulation or electrospinning [22]
FR / Barrier properties	Clay	Nanoclay e.g. montmorillonites (MMTs) for novel purpose of composite reinforcement [23]
FR properties	Phosphorus based agents	Non-halogen FRs, new sources of phosphorus (e.g. Phytic acid, Casein, DNA) Application by alternative methods: LbL [24]
Fibre Reinforced Composites	Non-biodegradable matrix: PES or PE, PA, PP reinforced with particles or fibres	Biodegradable matrix (PLA, PBA) and widely available fibres from ligno-cellulosic biomass (*Miscanthus gigantheus, Arundo Donax* or different cereals) [25]

Enzymes are still a hot topic in textile finishing. Up to now, they have been used for so many different purposes, starting from starch removal, scouring, mercerisation, bleaching, dyeing and dyestuff removal till softening, polishing, jeans treatments and wastewater bioremediation [26, 27]. The most frequent methods of their immobilization are presented in figure 4.

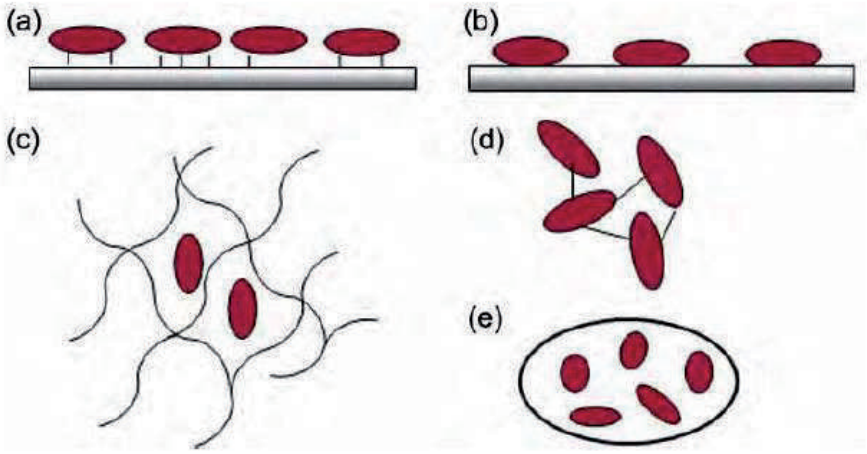


Figure 4: Methods of enzyme immobilization: a. covalent bonding; b. adsorption; c. entrapment in gel; d. intermolecular crosslinking; e. encapsulation [28]

Immobilized enzymes have proven to be very effective for commercial use in many cases. Their advantages over enzymes in solution are numerous, for example economy, greater stability and the possibility of easy removal from the reaction mixture, i.e. isolation. An additional advantage of binding the enzyme to a solid substrate is an increase in its resistance to changes in process parameters, pH or temperature [29].

One of the immobilization methods - encapsulation has drawn our interest the most. In the performed research microcapsules for medical purpose have been synthesized. Ethyl ether of cellulose was used for the shell and immortelle (*Helichrysum italicum)* essential oil was encapsulated in the core. Immortelle was chosen due to its anti-allergic, anticoagulant, antiseptic, diuretic, antibacterial, fungicidal, and anti-

inflammatory properties. Performed dermatological in-vivo testing proved safety of developed prototype, which can be used in the treatment of skin infections, allergic reactions, hematomas, scars or eczema.

Second type of developed prototype were cosmetotextiles with vitamine E for Wellness purposes. Final result was prototype of ethyl-cellulose microcapsules with α-tocopherol of high stability and effectiveness. Additionally, methods of α-tocopherol isolation from textile materials and its identification before and after washing were established. Obtained benefits were improved effectiveness of α-tocopherol, slow-release of microcapsules, so as enhanced durability of developed cosmetotextiles [30].

3.3. Textile Treatments

Textile products are characterized by an exceptionally large variety of raw material composition. Equally great diversity exists in the application of textile finishes, e.g. water and oil repellency, flame resistance, UV and antimicrobial protection, as well as functionalization for softness, ease of maintenance, etc. Textile finishing processes are responsible for the consumption of 20-25% of the world's total production of chemicals. The list of chemicals used in this sector includes more than 3,600 different colors and 8,000 chemicals, many of which pose a threat to human health and the environment. The textile industry is ranked among the top industries that pollute water precisely because of the consumption of a large amount of clean water, energy and most diverse chemicals (acids, salts, alkalis, textile auxiliaries, dyes, finishing agents).

Those data, so as the very strict regulations direct textile industry towards more frequent application of advanced textile treatments, such as plasma, microwave, ultrasound, LbL and super critical carbon dioxide ($scCO_2$). Several examples of high performance and advanced technologies application combined with environmentally friendly and sustainable agents for treatment of textile substrate are presented in table 2.

Table 3: Advances vs drawbacks of advanced technologies

Advanced technology	Advances	Drawbacks
Plasma	• No H_2O and waste H_2O (low pollution) • Atmospheric plasma can operate at ambient temperature • Possibility to treat hydrophobic surfaces after plasma pre-treatment (cleaning, etching, activating or polymerizing the surface) • Low consumption of electrical energy [31]	• Depending on the plasma type: Working under high pressure • High installation costs (device and supply of necessary gasses)
Microwave (MW)	• Min. H_2O and reduced waste H_2O • Reduced energy consumption • More uniform drying/curing • Fast treatment [32]	• High initial costs of planar device which requires more than 1 energy source (magnetron) • Leakage of MW energy in a case of too wide slot
Ultrasonic energy	• Min. H_2O and reduced waste H_2O (20-30%) • Reduction of bath temperature and treatment time • Intensification of textile treatments (increase of mass transfer and penetration of chemicals in fibers) [33, 34]	• Temperature limitations since the maximum effects of cavitation (formation of small bubbles in the liquid) occur at 49 °C
Layer-by-layer deposition (LbL)	• Min. H_2O and reduced waste H_2O • Possibility to treat hydrophobic surfaces after treatment with anionic bilayers (polycation/ polyanion) • Substitution of harmful chemicals and application of low concentration of environmentally benign ones [35]	• Durability to laundering • Process scaling up for industrial purposes
Super critical CO_2 ($scCO_2$)	• No H_2O and waste H_2O • No drying required = Energy savings • Savings up to 50% [36] • Recuperation of CO_2 and advanced heat exchanged design [37]	• High initial costs • High pressure process

The morphology of the functionalized fabrics was analysed by SEM and confirmed that no significant demages (e.g. fibrillation of fibers) occured at the surface after the performed advanced treatments. For example, ultrasonic energy acts at the solid-liquid interface when applied for the pretretment. In such heterogeneous system, the primary wall could be damaged in a case of efficient removal of impurities (added and natural ones) but those negative effects did not occure.

4. Contribution of EU funded projects

4.1. The role of design

One of the many projects funded by EU is Textile Toolbox, developed by Centre for Circular Design (CCD) at University of the Arts London, whose general idea was to propose design itself as the agent for change [38] The research team worked on a process of progressive problem solving to propose a new course of action to help their community improve its work practices. Figure 5 presents the scheme resulting from numerous worshops organized by the program Mistra Future Fashion [39], funded by The Swedish Foundation for Strategic Environmental Research (MISTRA).

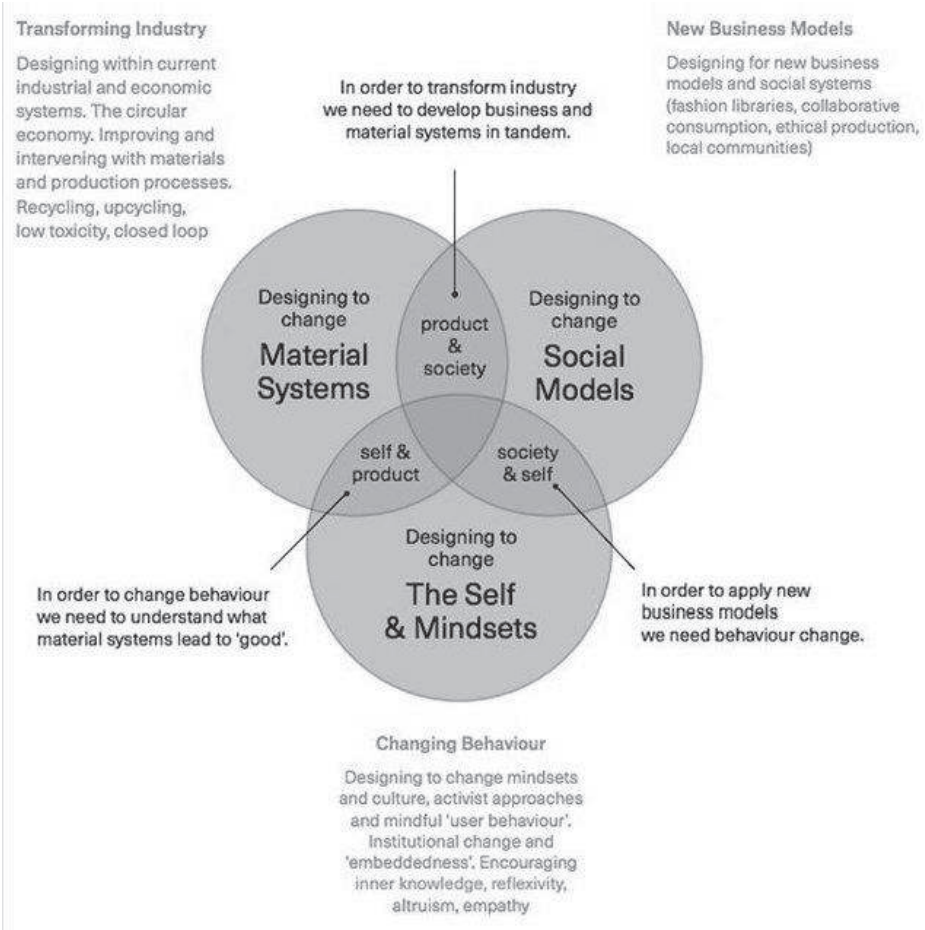


Figure 5: Materials, Models and Mindsets [40]

It is incredible how much can design activate positive changes and nurture pathways towards more sustainable way of living. Designers are actually considered to be Social Inovators who promote environmental and social impact of fashion and textiles on social media, conferences, blogs, exhibitions, festivals and publications [41].

Textiles have their own special purpose and combine beauty and aesthetic value in which they are designed with functionality and high efficiency. The ability to design materials with built-in structural, functional and aesthetic properties enables the adaptability of products for applications in various fields, such as fashion, interiors, automotive industry, architecture (construction industry) all the way to health and well-being.
[42]

Among the variety of possibilities, TTF's research group has focused primarily on automotive industry designing the prototypes of biocomposites developed following the principles of eco-design using green and

biodegradable chemicals and methods. Within the project *Advanced Textile Materials by Targeted Surface Modification* (ADVANCETEX) Mediterranean *Spartium junceum* L. plant, which is considered as weed in many parts of the World, was used as a filler in the production of novel biocomposites. On the other hand, novel and extremely popular PLA matrix was applied due to its biodegradable characteristics. PLA can be produced from corn, rice or rape [43] and therefore is an excellent substitute for presently applied matrixes, which are still mostly produced from non-sustainable PP fibers which require oil for its production. Two types of fibers were used to produce biocomposites: long fibres/oriented and short fibres/random, as presented in fig.6. When long fibers are used with thermoplastic matrix numerous advantages can be expected. Such LFT (long fibre-reinforced thermoplastic) composites possess excellent specific modulus and strength, impact and corrosion resistance, so as ease of processability and recyclability. These advantages classify LFT composites in the group of the most advanced lightweight engineering materials [44].

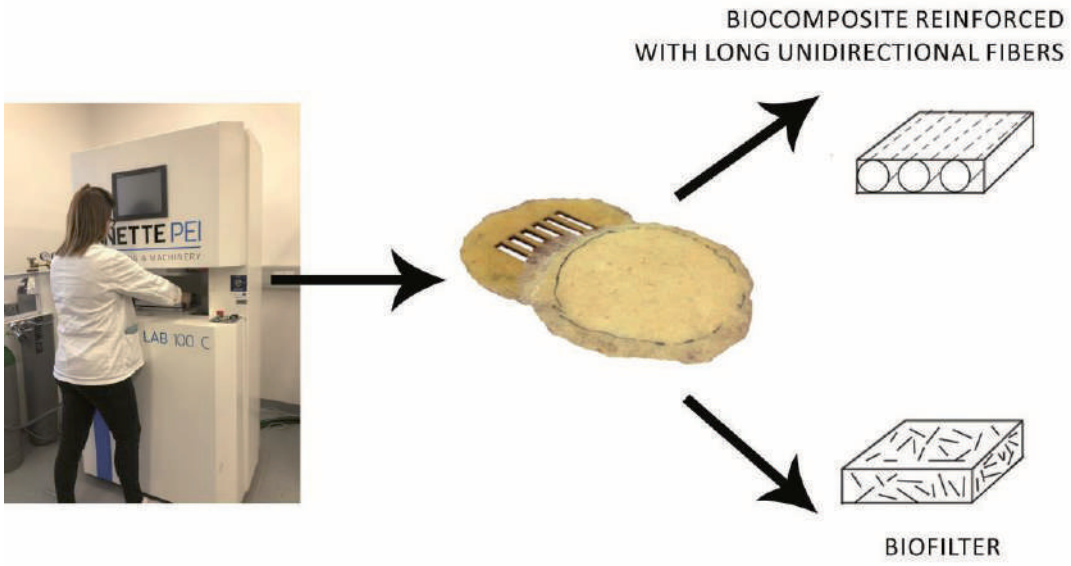
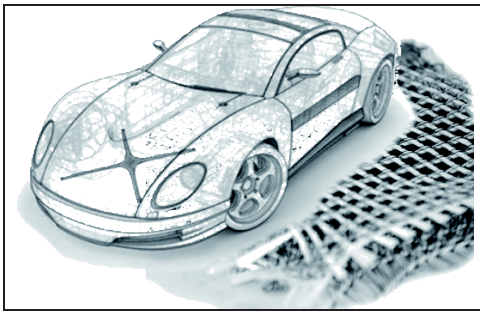


Figure 6: Design of sustainable and biodegradable biocomposite material composed of PLA matrix and natural fibre reinforcement

The project ADVANCETEX addressed the possibility of application of wariety of domestic and traditional bast fibers (flax, linen, Spartium junceum) for the revitalization of sustainable fibers production. Project resultetd with eight prototypes where two of them are dealing with biocomposites, developed primarily for the automotive industry (Figure 7).



Biocomposite

Result: Eco-design of biocomposite for automotive industry.

Bio-nanocomposite

Result: Development of effective surface and chemical treatments to improve poor interfacial adhesion between fibers and polymer matrix.

Figure 7: Biocomposite prototypes developed within ADVANCETEX project [45]

The aim of first prototype was development of biodegradable biocomposites composed of sustainable bast fibers (eg. *Spartium junceum* L. and/or flax fibers) reinforcement and PLA biopolymer with enhanced mechanical and thermal characteristics, applied as matrix. Benefits are: fulfillment of automotive industry requirements for lighter cars and reduced gass emissions, with benefits for our eco-system.

The aim of second prototype (BIO-NANOCOMPOSITE) was development of innovative technical textiles from *Spartium junceum* L. and PLA biopolymer modified with environmentally friendly nanoparticles with precisely targeted properties. Benefits are in accordance with REACH regulation and EU legislation on environmental issues for composite industry.

Nowadays, we are speaking about novel sustainable fibres, but in fact, most of them have been used in the past, and now we are trying to revitalize them due to the new sustainability initiatives to grow fibres in our neighbourhood. These initiatives confirm dependence and interlinkages of design and sustainability.

4.2. Addressing the Sustainability Issues

PROJECT BIOCOMPOSITES

Issues of eco-design and sustainability are combined within TTF's running project *Design of Advanced Biocomposites from Sustainable Energy Resources* – BIOCOMPOSITES [46]. Furthermore, the project is following the objectives of the updated Bioeconomy Strategy [47]. Biocomposites is led by University of Zagreb Faculty of Textile Technology and has one partnering institution, University of Zagreb Faculty of Agronomy. Both institutions share the responsibility to support the sustainable and circular bio-based sector, through the project activities.

Figure 8: Quantified Socioeconomic Indicators of the EU Bioeconomy in 2015: number of persons employed, turnover, value added and apparent labour productivity [48, 49]

The project will make significant contribution to 2 areas: Agriculture (which provides 9.2 million jobs and holds first place) and Bio-based textiles (which provides 1.0 million jobs and holds fifth place), as presented in Figure 8.

The general project idea is to apply biomass for two purposes – to produce fibers to be used as reinforcement of composite matrix and the rest is used for biofuels production. Until now, biomass has been mostly exploited by direct application of energy plants for the biofuels but within this project valuable cellulose fibers are extracted first and the rest of the ligno-cellulose biomass, which is in the textile industry considered as waste, will be used to produce biofuels. In the conventional (linear) production of fiber-reinforced composites, a large amount of waste material (cca 80%) created a big problem, which is fully utilized in this project for the production of biofuels. So far, this waste has not been used because it was previously treated with alkali, which prevented its further use. This project envisages the development of a new environmentally friendly pretreatment process and the whole waste from the production will be used to

create bioenergy. By transferring knowledge from one area to another, the input raw biomass gained multi-purpose usage in the production of biocomposites and bioenergy.

PROJECT CLIMATE

Project: *Production of food, biocomposites and biofuel from cereals in circular bioeconomy (CLIMATE)* is facing the global problem of climate changes [50].

As part of the project, the correctness of agrotechnical measures for old and new varieties of wheat and barley and corn hybrids was tested in order to determine the optimal ratio of grain to biomass, so as the presence of mycotoxins. In addition to the quantity, the quality of cereal grains for food and nutrition, carbon sequestration in the soil and plants was also investigated. The quality of biomass and the possibility of using residues from the production of biocomposites and biofilters for the production of second-generation bioethanol and solid biofuels were also verified. By utilizing the remains from one production, its potential waste will become the raw material of another industry and the circular bioeconomy process will be closed. This project raised the awareness of the general public about the possibilities of mitigating the negative effects of climate change.

The development of society inevitably leads to a growing need for food and energy production, and thus to increased emissions of greenhouse gases into the environment. Humans and ecosystems rely on soil that allows plants to grow and develop and regulates the water cycle. Also, soil is the third largest carbon storage on Earth, so it is a major factor in the fight against climate change. One of the fundamental challenges of modern agricultural production are based on the challenges caused by climate change. Climate change, through temperature extremes, droughts, and intense precipitation in a short period of time, the emergence of new harmful organisms, significantly affect the achieved yields and quality of cultivated food.

Taking into the consideration that the combustion of fossil fuels contributes with more than 90% of total emissions of the energy sector, as one of the possible solutions to reduce part of global emissions, the production and use of biomass and biofuels is imposed. According to: An EU Strategy for Biofuels [51], biomass is defined as the biodegradable part of products, residues and waste from agriculture (including plant and animal substances), forestry and related industries, so as the biodegradable part of industrial and municipal waste. As an energy source, it represents a raw material during the process of conversion into liquid, gaseous and solid biofuels. Biomass can be removed by photosynthesis, part of the atmospheric carbon by sequestration of carbon into the soil and biomass of crops, which can be one of the potential measures to mitigate climate change. Also, by applying appropriate agro-technical measures and proper selection of cultures, it is possible to maintain/increase soil fertility or build soil organic matter (humus) and reduce greenhouse gas emissions into the atmosphere.

Depending on the type of raw material used in the production of biofuels can be divided into: first, second and third generation. Compared to the first generation of biofuels (bioethanol, biodiesel and biogas) obtained from sugar, starch, vegetable oils or animal fats, during the production of the second generation no raw materials are used that also serve as food for humans and animals, but are obtained exclusively from residues of agricultural production, forest waste or cultivation of energy crops. Biomass has three basic applications: (i) heat and/or electricity generation, (ii) transport fuel, and (iii) chemical feedstock.

Furthermore, the new bioeconomy strategy for a sustainable Europe from 2018 [47] defines the basic principles related to (I) increasing and strengthening bioindustrial sectors, (II) rapid introduction of the bioeconomy across Europe, (III) ecosystem protection while understanding the ecological constraints of the bioeconomy. At the same time, this strategy defines agricultural biomass through 4F biomass management (food, feed, fuel and fiber).

In addition to the 21st United Nations Convention on Climate Change, The Paris Agreement – *Conference of the Parties on its 21st session* (COP 21) and *Biofuels and Indirect Land Use Change* (ILUC) [52] highlight the great potential that soil must absorb carbon and thus mitigate climate change. Biomass and biofuels are characterized as an important segment in Europe's quest to become a self-sustaining, low-carbon society. Based on the results of the CLIMATE project, preconditions are fulfilled for the creation of sustainable soil management. The project proved that chosen traditional cultures (maize, wheat and barley) are more resistant to climate changes than the new ones – so again, we are back to the past!

5. Conclusions

The textile industry has been continuously criticized for being one of the biggest polluters and consumers of water in the world. The fact that 20-25% of the world's total production of chemicals is used for textile

processing tells us how polluting the textile industry really is. Educated employees are the ones who can lead to change. The goal of all today's initiatives is to reduce the amount of waste already at the source, recycling, composting, regeneration, and only at the very end disposal of the remaining waste. In this last step, attention should be paid to ensure that disposal is carried out in the best and safest way for people and the environment.

It is The European Green Deal that can play a significant role in the proces of industry transformation towards full embracement of circular economy. Defining the guidelines, measures and laws that each Member State must implement, makes it easier to act to reduce pollution. The Green Deal prescribes measures in accordance with the ecological limitations of nature, which are smaller today than ever before. By involving all member states and adhering to measures, Europe could become the first climate-neutral continent. Evenmore, if countries outside our continent will participate in the European Green Deal, positive changes could be felt at the global level. Only a joint effort and directing all of humanity back to the "right path" can return our planet to the state it was in before the mass pollution and unfavorable anthropogenic impact.

Huge change happened in 2009, when United Nationes declared the International Year of Natural Fibers (IYNF) and promoted the trend „back to the nature“. Today, we are lookig back to the past and using old habbits of minimal throwing away, so as the taking from the Nature the sources which are already offered by the Nature.

Most of today's research is conducted with the aim of using less harmful compounds and chemicals, both for humans and the environment. Our everyday life must become application of solely environmentally friendly agents, devices and processes, as well as the development of awareness and education about the importance of biodiversity and environmental protection.

Only in this way we can ensure the future of the textile industry, so as the other industries. Within this paper different environmentally friendly and energy efficient methods of microwave, ultrasound or plasma modifications were presented. Each of those methods can achieve desired targeted functionalities when applied on the surface of fibres, textiles, clothing or inlayers for footwear.

One of the trends nowadays is application of well-known agents of proved efficiency using novel high-performance technologies with reduced environmental footprint, e.g., plasma, microwaves, electrospinning, or Layer-by-Layer (LbL) deposition. In this way, old knowledge is merged with the innovative ideas and what was good in the past is not forgotten. It is the other way around – new design process is from the very beginning including only sustainable, widely available, environmentally friendly materials, processes, devices and fulfil very strict regulations. In this circle each of us can make a significant contribution!

References

[1] A Strategic Research and Innovation Agenda to underpin the EU Strategy for Sustainable and Circular Textiles: Ready to Transform, European Technology Platform for the Future of Textiles and Clothing, Brussels (2022)
[2] Circular Textiles-Prospering in the Circular Economy, EURATEX, Brussels (2020), *Available at:* https://euratex.eu/wp-content/uploads/EURATEX-Prospering-in-the-Circular-Economy-2020.pdf *Accessed:* 3rd August 2022
[3] Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F.: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, World Bank (2018), DOI: 10.1596/978-1-4648-1329-0
[4] Andersen, M. S.: An introductory note on the environmental economics of the circular economy, *Sustainability Science*, **2** (2007) 1, pp. 133-140
[5] Pinjing, H., Fan, L., Hua, Z., Liming, S.: Recent Developments in the Area of Waste as a Resource, with Particular Reference on the Circular Economy as a Guiding Principle, *Waste as a Resource*, The Royal Society of Chemistry, London, (2013) pp. 144-161
[6] *Available at:* https://depositphotos.com/179713140/stock-illustration-circular-and-linear-economy-compared.html *Accessed:* 25th July 2022
[7] Towards a Circular Economy: A zero waste programme for Europe, COM(2014) 398 final, European Commission (2014)
[8] A new Circular Economy Action Plan – For a cleaner and more Competitive Europe, COM(2020) 98 final, European Commission (2020)
[9] Ellen MacArthur Foundation, A new textiles economy: Redesigning fashion’s future (2017) *Available at:* http://www.ellenmacarthurfoundation.org/publications, *Accessed:* 1st July 2022
[10] The European Green Deal, COM(2019) 640 final, European Commission (2019)

[11] Closing the loop – An EU action plan for the circular economy, COM(2015) 614 final, European Commission (2015)
[12] Chemicals strategy for sustainability Towards a toxic free environment, COM(2020) 667 final, European Commission (2020), Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf, *Accessed:* 25th July 2022
[13] Orsag, B. et.al.: Impact of The European Green Deal on pollution reduction in textile industry with an emphasis on textile finishing, *Tekstil*, **69** (2020) 1-3, pp.34-44, ISSN 0492 - 5882
[14] Dorotić. I. et.al.: Boosting the efficient use of resources in the textile industry by moving to a circular economy, *Tekstil* **68** (2019) 10-12, pp. 236-247, ISSN 0492 – 5882
[15] Europa 2020: European strategy for smart, sustainable and inclusive growth COM (2010) 2020, *Available at:* https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF, *Accessed:* 2nd April 2022.
[16] Reference Document on Best Available Techniques for the Textiles Industry (2003), *Available at*: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/txt_bref_0703.pdf, *Accessed:* 3rd May 2022
[17] Kovačević, Z., Bischof Vukušić, S., Zimniewska, M.: Comparison of Spanish broom (*Spartium Junceum* L.) and flax *(Linum usitatissimum*) fibre, *Textile Research Journal* **82** (2012) 17, 1786-1798, doi:10.1177/0040517512447526, ISSN: 0040-5175
[18] Peran, J., Ercegović Ražić, S., Sutlović, A., Ivanković, T., Glogar, M. I.: Oxygen Plasma Pre-Treatment Improves Dyeing and Antimicrobial Properties of Wool Fabric Dyed with Natural Extract from Pomegranate Peel, *Coloration technology* **136** (2020), 2, 177-187, doi:10.1111/cote.12464, ISSN:1478-4408
[19] Fijul Kabir, S.M., Chakraborty, S., Azizul Hoque, S.M., Mathur, K.: Sustainability Assessment of Cotton-Based Textile Wet Processing, *Clean Technology* **1** (2019) 232–246; doi:10.3390/cleantechnol1010016, ISSN: 2571-8797
[20] Turalija, M., Gaan, S., Schoenzholzer, L.M., Guimond, S., Koerner, E., Hanselmann, B., Heuberger, M., Bischof Vukusic, S.: Antimicrobial Polylactide, Book of Proceedings (5th International Textile, Clothing & Design Conference – Magic World of Textiles), Dragčević, Z., Hursa Šajatović, A.; Vujasinović, E. (ed.) Zagreb, University of Zagreb Faculty of Textile Technology, (2010) Dubrovnik, Croatia, pp.160-165, ISSN 1847-7275
[21] Magovac, E., Bischof, S., Grunlan, J., Jordanov, I.: LBL Deposition – An Innovative Method of Surface Modification of Cotton with Enhanced FR Properties, Book of Proceedings (9th International Textile, Clothing & Design Conference - Magic World of Textiles), Dragčević, Z.; Hursa Šajatović, A.; Vujasinović, E. (ed.) Zagreb, University of Zagreb Faculty of Textile Technology (2018) pp. 132-136, ISSN 1847-7275
[22] Matijević, I., Pušić, T., Bischof, S. Šauperl, O., Volmajer Valh, J.: Synthesis of α-tocopherol microcapsules and it's grafting onto cotton fabric, Book of Proceedings (8th International Textile, Clothing & Design Conference, Dragčević, Z., Hursa Šajatović, A., Vujasinović, E. (ed.). Zagreb. University of Zagreb Faculty of Textile Technology, Zagreb, Croatia (2016) pp. 189-194, ISSN 1847-7275
[23] Kovačević, Z., Jurišić, V., Bischof, S., Krička, T.: Modification of Spartium Junceum L. fibers by Nanoparticles, Proceedings of the 4th International Conference on Natural Fibers - Smart Sustailable Solutions, Fangueiro, R. (ed.) Porto, Portugal, Tecminho-Associacao Universidade-Empresa para o Desenvolvimento (2019) pp. 104-105, ISBN 978-972-8600-30-3
[24] Magovac, E., Bischof, S.: Non-halogen FR treatment of cellulosic textiles, Tekstil **64** (2015) 9-10, pp.285-309, ISSN 0492 - 5882
[25] Krička, T., Grubor, M,, Kovačević, Z., Bilandžija, N., Matin, A., Bischof, S.; Possibility of using energy cultures for fiber production, Proceedings of the 4th International Conference on Natural Fibers-Smart Sustailable Solutions, Fangueiro, R. (ed.) Porto, Portugal, Tecminho-Associacao Universidade-Empresa para o Desenvolvimento (2019) pp. 358-359, ISBN 978-972-8600-30-3
[26] Chatha S.A.S., et al.: Enzyme-based solutions for textile processing and dye contaminant biodegradation- a review, *Environmental Science and Pollution Research* **24** (2017), pp.14005-14018, ISSN: 09441344
[27] Kirk O. et al.: Industrial enzyme applications, *Current Opinion in Biotechnology*, **13** (2002) 4, pp. 345-351, ISSN: 2590-2628
[28] Gulrajani, M.L., Gupta, d.; Emerging techniques for functional finishing of textiles, *Indian Journal of Fibre & Textile Research* **36** (2011) 12, pp.388-397, ISSN 0975-1025
[29] Homaei, AA., Sariri, R., Vianello, F, Stevanato, R.: Enzyme immobilization: an update, *Journal of Chemical Biology* **6** (2013) 4, pp.185–205, doi: 10.1007/s12154-013-0102-9
[30] Matijević, I., Šauperl, O., Bischof, S.: Application of ethyl cellulose microcapsules with *Helichrysum italicum* essential oil on modal and cotton fabric, 91st Textile Institute World Conference - Integrating Design with Sustainable Technology, Leeds, UK, (2018) 23.-26.07.2018, ISBN 9781713834441
[31] Ercegović Ražić, S., Čunko, R.: Modification of Textile properties Using Plasma (in Croat), *Tekstil* **58** (2009) 3, pp. 55-74, ISSN 0492 – 5882

[32] Katović, D., Bischof Vukušić S., Flinčec Grgac S.: Application of Microwaves in Textile Finishing Processes (in Croat.), *Tekstil* **54** (2005) 7, pp. 319-325, ISSN 0492 – 5882
[33] Thakore, K.A., Abate B.: Application of Ultrasound in the Pretreatment of Cotton Fabric, *Cellulose Chemistry and Technology* **51** (2017) 9-10, pp. 983-992, ISSN: 5769787
[34] Nazmul Islam, G.M., Ke, G., Md. Ahsanul Haque A.N., Md. Islam, A.: Effect of ultrasound on dyeing of wool fabric with acid dye, *International Journal of Industrial Chemistry* (2017), DOI 10.1007/s40090-017-0131-2, ISSN 22285547
[35] Šimić, K., Bischof, S., Soljačić, I.: The Application of Layer-by Layer Deposition on Textiles (in Croat) Tekstil **64** (2015) 11-12, pp. 358-368, ISSN 0492 – 5882
[36] Eren, H. et al.: Supercritical carbon dioxide for textile applications and recent developments, IOP Conference Series Materials Science and Engineering **254** (2017) 082011
[37] Alsagri, A.S., Wang, X.: Performance improvement of supercritical carbon dioxide power cycles through its integration with bottoming heat recovery cycles and advanced heat exchanger design: A review, International *Journal of Energy Research* **44** (2017) 9, pp. 7108-7135, ISSN: 0363-907X, doi.org/10.1002/er.5319
[38] *Available at:* http://www.textiletoolbox.com/ *Accessed:* 16th April 2022
[39] Available at: http://mistrafuturefashion.com/output/teds-ten/ *Accessed:* 20th July 2022
[40] Early, R.: Designing Fast & Slow. Exploring fashion textile product lifecycle speeds with industry designers, *The Design Journal* **20** (2017) 1, pp. S2645-S2656, DOI: 10.1080/14606925.2017.1352776, ISSN: 14606925
[41] Early, R., Goldsworthy, K.: Circular Textile Design: Old Myths and new Models, in: Designing for the Circular Economy (Charter, M.) Routledge, (2018)
[42] Valentine, L. et al.: Design Thinking for Textiles: let's make it meaningfull, *The Design Journal* **20** (2017) 2, pp. S964-S976, DOI: 10.1080/14606925.2017.1353041, ISSN: 14606925
[43] Hagen, R.: Polylactic Acid, in: Polymer Science: A Comprehensive Reference, **10** (2012) pp. 231-236, https://doi.org/10.1016/B978-0-12-803581-8.01530-7
[44] Ning H. et. al: A review of Long fibre-reinforced thermoplastic or long fibre thermoplastic (LFT) composites, *International Materials Reviews* (2019), DOI: 10.1080/09506608.2019.1585004, ISSN:1743-2804
[45] ADVANCETEX brochure, (Eds: Bischof, S., Pušić, T., Vujasinović, E.), University of Zagreb Faculty of Textile Technology, Zagreb, 2019, ISBN 978-953-7105-74-7
[46] BIOKOMPOZITI project page, *Available at:* https://biokompoziti.eu/ Accessed: 16th April 2022
[47] A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment: updated bioeconomy strategy, European Commission, Directorate-General for Research and Innovation (2018), *Available at:* https://data.europa.eu/doi/10.2777/792130, *Accessed:* 15th May 2022
[48] Follador, M., Philippidis, G., Davis, J., Soares Filho, B.; Assessing the impacts of the EU bioeconomy on third countries, Publications Office of the European Union, Luxembourg (2019) ISBN 978-92-76-09820-1, doi:10.2760/304776, JRC117364.
[49] Ronzon, T., M'Barek, R.: Socioeconomic Indicators to Monitor the EU's Bioeconomy in Transition, *Sustainability* **10** (2018) 6, pp.1745, doi: 10.3390/su10061745, ISSN 2071-1050
[50] CLIMATE project page, *Available at:* https://projekt-klima.eu/, *Accessed:* 2nd May 2022
[51] An EU Strategy for Biofuels, COM(2006) 34 final, European Commision, *Available at:* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006DC0034&from=EN, Accessed: 15th August 2022
[52] Biofuels and Indirect Land-Use Change (ILUC), Commentary Report, State of Sustainability initiatives (2016), *Available at*: https://www.iisd.org/ssi/wp-content/uploads/2019/09/Biofuels_publications-1.pdf, Accessed: 15th May 2022

Author(s):

Prof. Sandra BISCHOF, Ph.D.
University of Zagreb, Faculty of Textile Technology, Department of Textile Chemistry & Ecology
Prilaz baruna Filipovića 28a, HR-10000 Zagreb, Croatia
Phone: +(385) (1) 4877351 Fax: +(385) (1) 4873351 E-mail: sbischof@ttf.unizg.hr