# BULLETIN



SPECIAL ISSUE ON

Additive Manufacturing (AM)

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#### CONTRIBUTE TO THE

### CSME Bulletin

We welcome submissions of events, announcements, job postings and feature articles relevant to mechanical engineering from researchers and engineers in Canada.

Please send your input to: bulletin@csme-scgm.ca

### Editor's Letter



IT IS A GREAT PLEASURE TO INTRODUCE YOU to the spring 2018 issue of the CSME Bulletin. Together with Professor Marc Secanell Gallart, we have put together an issue focused on the exciting theme of Additive Manufacturing (AM). This field of research and development has gained a lot of attention and momentum in academia and industry in recent years. Technologies such as 3D printing, rapid prototyping and direct digital manufacturing are introducing fascinating and revolutionary advancements to the field of manufacturing.

Manufacturing is one of the largest industries in Canada and research on AM, and more specifically 3D printing, has been growing rapidly among university and college researchers as well as the manufacturing industry. In the Featured Articles section of this issue, you can read more about the recent Canadian investments in AM and the exciting advancements pursued by Professors Ehsan Toyserkani, Mohsen Mohammadi, and Yaoyao Fiona Zhao from the University of Waterloo, University of New Brunswick and McGill University, respectively. You will learn about the strategic Pan-Canadian network led by the University of Waterloo involving six other universities and 14 companies as well as a recently developed AM technology at the University of New Brunswick that is going to revolutionize the marine industry worldwide. Dr. **Tonya Wolfe**, a senior metallurgical engineer at InnoTech Alberta, has been interviewed in the Alumni O&A section.

In addition to our focus articles on AM, we have also included several articles relevant to Canadian mechanical engineers, such as the one by the newly appointed chair of the Department of Mechanical Engineering at the University of Alberta, Professor **John Doucette**, who provides

us with his perspectives on "the ability [of a department chair] to influence the culture and set the direction of the department". This article fits nicely with the *New Faculty Spotlight* section, introducing the remarkable new researches of colleagues in Central Canada, i.e. Professors **Amirkianoosh Kiani** from University of Ontario Institute of Technology, **Brian Vermeire** and **Tsz Ho Kwok** from Concordia University, and **Hamidreza Abdolvand** from University of Western Ontario. Professor **Amy Bilton**, Technical Editor of the CSME *Bulletin*, has once again provided us with two great ME news pieces. We have made a small change to this section of the *Bulletin*, allocating one of the news pieces to an article from the CSME *Transactions* which will be selected by the editor of this journal from now on. To conclude the issue, Dr. **Marina Freire-Gormaly**, as the newly appointed Chair of Student Affairs at CSME, has provided this issue's *Student Chapter Report*.

Finally, it is with great sadness that we need to inform CSME members that Professor **Sushanta Mitra's** term as CSME President has come to an end. Professor **Maciej Floryan** will step-in as the next President of CSME. We wish both the best and look forward to Maciej's leadership and to working with him on future issues of the CSME *Bulletin*.

The CSME *Bulletin* will continue to focus on emerging areas in Mechanical Engineering. For instance, we are considering having future issues on artificial intelligence (AI), biomedical engineering, sustainable energy, and advanced materials. We would be delighted to receive your contributions and comments about the CSME *Bulletin* as well as your ideas to improve it in the future. We invite you to enjoy reading this issue on AM.

Paywayir

POUYA REZAI, PhD, P.Eng., MCSME Editor-in-Chief CSME Bulletin Assistant Professor Department of Mechanical Engineering Lassonde School of Engineering York University





MARC SECANELL GALLART, PhD, P.Eng., MCSME Associate Editor CSME Bulletin Associate Professor Department of Mechanical Engineering University of Alberta



## **President's Message**

Dear CSME Members.

I WRITE THIS MESSAGE WITH MIXED EMOTIONS. AS MY TERM AS PRESIDENT OF THE CSME ENDS

by this May, and I move to immediate Past President, I experience a sense of emptiness and at the same time a feeling of pride to have led such a great Canadian professional society for mechanical engineers over the last two years. Under my term, we have seen significant changes including a growth in membership, both individual and sustaining Canadian university departments, a total revamp of CSME's website with a new online membership system, and a smooth transition of the *Transactions* of the CSME to a more professionally managed process under Canadian Science Publishing and appointment of its inaugural editor. All these could be possible because of the tremendous support received from the Executives, the Board and the countless volunteers that make this a vibrant organization.

As you have read in my earlier communications, one of my priorities has been to bring greater gender diversity to the CSME. Pending approval from the members at the upcoming annual general meeting in May, I am happy to inform you that the next senior vice-president of CSME will be Prof. **Mina Hoorfar**, a long-term volunteer of CSME. I am confident that she will work closely with the upcoming president of CSME, Prof. **Maciej Floryan**, and take this organization to new heights. I wish both Maciej and Mina great success and I look forward to have more conversations with you at our annual general meeting on May 29<sup>th</sup> at the Lassonde School of Engineering, York University.

Sincerely,

SUSHANTA MITRA, PhD, P.Eng., FCSME, FEIC, FCAE, FAAAS CSME President

Surtanta

Professor, Mechanical and Mechatronics Engineering, University of Waterloo Executive Director, Waterloo Institute for Nanotechnology

### Message du président

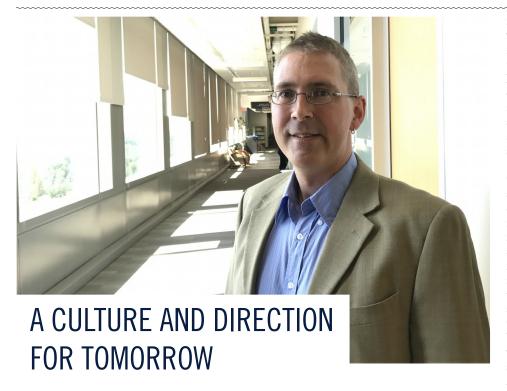
Chers membres de la SCGM,

J'écris ce message avec des émotions mélangées. Comme mon mandat de président du CSME prend fin d'ici le mois de mai et que je passe à la présidence immédiate, j'éprouve un sentiment de vide et en même temps un sentiment de fierté d'avoir dirigé une si grande société professionnelle canadienne pour les ingénieurs mécaniciens. deux dernières années. Durant mon mandat, nous avons constaté des changements importants, notamment une augmentation du nombre de membres, des départements universitaires canadiens et individuels, une refonte complète du site Web de CSME avec un nouveau système d'adhésion en ligne et une transition en douceur des transactions du CSME vers un processus géré par Canadian Science Publishing et nomination de son éditeur inaugural. Tout cela pourrait être possible en raison de l'énorme soutien reçu des cadres, du conseil d'administration et des innombrables bénévoles qui en font une organisation

Comme vous l'avez lu dans mes communications précédentes, l'une de mes priorités a été d'apporter une plus grande diversité de genre au CSME. Dans l'attente de l'approbation des membres lors de la prochaine assemblée générale annuelle en mai, je suis heureux de vous informer que la prochaine viceprésidente principale du CSME sera la professeure Mina Hoorfar, une bénévole à long terme du CSME. Je suis confiant qu'elle travaillera en étroite collaboration avec le prochain président du CSME, Prof. Maciej Floryan, et portera cette organisation vers de nouveaux sommets. Je souhaite beaucoup de succès à Maciej et à Mina et j'ai hâte d'avoir plus de conversations avec vous lors de notre assemblée générale annuelle, le 29 mai, à la Lassonde School of Engineering de l'Université York.

Cordialement,

Président





#### DR. JOHN DOUCETTE, PhD, P.Eng.

Dr. Doucette is a Professor in the Department of Mechanical Engineering at the University of Alberta, previously served as Associate Chair (Graduate) from 2014 to 2017, and has been Chair since 2017. He completed a BSc in Mathematics from Dalhousie University, a BEng in Industrial Engineering from the Technical University of Nova Scotia, and a PhD in Electrical and Computer Engineering from the University of Alberta. He held Research Scientist and Research Engineer positions at TRLabs from 2000 to 2005, and joined the Department of Mechanical Engineering in 2005. He carries out research in network restoration and protection, reliability and availability, and various applications of operations research and optimization.

#### AT MY INSTITUTION, AND AT MANY OTHERS

in Canada, department chairs hold precious little real authority, the most obvious being the setting of teaching assignments and the limited assignment of administrative-type duties. Prior to taking on my current role, I sought out and received the sage advice of several current and former chairs, which greatly helped prepare me for the changes that were to come for my typical week at the office. But there was one aspect of the job that none of those wise compatriots mentioned, a privilege enjoyed by a chair that supersedes all of those administrative functions that come with the position, and which will last long after the chair's term has passed. I'm referring to the ability to influence the culture and set the direction of the department. Not strictly steering the ship, per se, but suggesting a destination, choosing the stars to navigate by, and guiding the selection of new crewmembers to accompany us on the voyage. And my predecessors have done that well.

Under their guidance, our department has seen substantial growth in the thirteen years since my arrival here. At least in terms of years of service (I won't try to count grey hairs), we are a young department. Our current complement of academics is 51 full-time professors at various stages of their careers, over half of which have been here for fewer than ten years. And I wouldn't trade a single one of them for the very best found elsewhere. One might expect that given our geographical location, we must be dominated by those whose research activities relate to energy. While we certainly have some prominent researchers in energy-related fields, my colleagues' expertise and active research programs span the breadth of mechanical engineering and in many cases go beyond. Of relevance to the current issue of this bulletin are our research programs that intersect additive manufacturing in various ways. Our recent chairs had the foresight to bring on board a number of young professors who incorporate 3D printing as a tool, and most importantly, some who actively carry out research on the topic, thereby setting us on the path to build our department and move us in this important direction.

Among the latter are two recent additions to our department. Dr. Rafiq Ahmad's research activities include integration of traditional machining approaches with additive manufacturing, multi-material 3D printing, laser-assisted manufacturing and joining of dissimilar materials, and optimized path-planning for load-bearing 3D printed parts. Dr. Ahmed Qureshi's research activities focus on design and manufacturing, with specific interests in tolerancing in additive manufacturing, bio-printing, and variation management in thermoplastic 3D printing. We also have others in the department whose work incorporates additive manufacturing in a number of ways. To name a few, Dr. Cagri Ayranci's work involves braided and braid-reinforced composite materials in 3D printing, Dr. James Hogan utilizes 3D printing in his work on industrial processes for next generation materials, and Dr. David Nobes uses a cluster of 3D printers to produce components and parts for his experimental apparatuses that would be difficult to produce using conventional machining. Expected outcomes of their collective work include stronger components with physical characteristics and properties better suited to their intended purposes, a better understanding of 3D printing material properties, and safer and more efficient manufacturing approaches.

With this growing corps serving as a foundation, we are now recruiting in two related areas; manufacturing and industrial engineering, and mechatronics engineering. The intention is that this current recruitment will serve to build on existing strengths while adding new capabilities and expertise that complement what we already have in place. My hope is that this will also afford us the opportunity to make additional progress on moving our department's culture. As we discovered in a recent strategic planning exercise, many of the key objectives identified by a broad cross section of the department were to explicitly develop department policies that promote collegiality and collaboration. I view this as another win of recent hiring decisions and leadership enjoyed by our department in recent years, and says a lot of the values we mutually hold. There is one area in particular, however, that I feel we need to do a better job with, and not necessarily in my own department specifically, but more broadly.

As an astute friend and colleague said to me just a week or two ago, and I paraphrase, "we [(engineering professors)] are here in these roles ...continued page 19

### **ADDITIVE MANUFACTURING:**

# A KEY ENABLER OF ADVANCED MANUFACTURING



#### DR. EHSAN TOYSERKANI, PhD, P.Eng.

Dr. Toyserkani is a Professor and University Research Chair in Additive Manufacturing in the Department of Mechanical and Mechatronics Engineering at the University of Waterloo. He has been working on different aspects of additive manufacturing since 2000, where he has published more than 75 journal papers, one textbook, one edited book, and 6 pending and granted patents. He is leading a National Additive Manufacturing Strategic Network in Canada and has been involved in many international and national advisory boards and evaluation committees such as NSERC Strategic Partnership Projects in Advanced Manufacturing Theme. He is currently a member of the editorial board of several journals and regional editor of the journal Lasers in Engineering.

#### ADDITIVE MANUFACTURING (AM) IS A LAYER-

by-layer fabrication technology "poised to be one of the most valued forms of manufacturing in history"1. Also known as 3D printing, AM represents a synergy of mechanical, chemical, electrical, material and computer engineering. Parts are fabricated directly from digitized designs, and their precise geometries and material gradients can normally offer higher performance than parts assembled using conventional techniques. Material waste and energy costs can be minimized, and rapid prototyping and on-demand manufacturing can accelerate the design-to-market cycle. The next generation of AM machines that must be intelligent will play an important role in the digital transformation of manufacturing known as Industry 4.0. McKinsey estimates that by 2025, the global economic impact will approach \$550 billion per year<sup>2</sup>.

The greatest impacts will come through the additive manufacturing of *metal* parts. Substantial progress has been made in recent years; however, there are remaining challenges facing widespread industry adoption: (1) the need for an expanded range of feedstock metal materials; (2) the need for health and safety criteria for handling AM metal powders; (3) the need for faster build rates and greater build volumes; (4) the need for increased process repeatability and reliability; (5) the need for greater education on design practices; (6) and the need for uniform standards for the certification of AM parts.

A major shortcoming among the abovementioned issues in the area of metals, metal alloys and metal matrix composite is a shortage of validated powders for the utilization in commercially available metal 3D printers, including laser, electron beam and binder-based AM processes. For instance, more than 1,000 ferrous alloys are commercially available for conventional manufacturing such as casting, machining and forming; however, only a handful number of ferrous alloys have been verified for AM systems and limited production by original equipment manufacturers. For aluminum alloys, the ratio between conventional alloys and validated AM powders is approximately 600 to 14. Customiza-

tion and validation of AM metal powders and introducing them to the market usually takes years of research and development. For these reasons, the number of components being made and companies that can benefit from AM has been limited. In addition, cost of relatively few metal AM powders available for sale is multiple times more than raw materials for conventional manufacturing. Low volume sales of metal AM materials (i.e., around \$400M in 2016 that is a small fraction of the overall raw materials market) may attribute to this issue. However, as the AM adoption escalates, prices are expected to fall substantially while more materials are adopted for AM processes. Opportunities are tremendous to enhance powder production methods awhile formulating entirely new powders.

There are also tremendous opportunities in the area of computer modelling of AM processes to support the process parameters optimization via reliable and validated simulation rather than costly experimentation. Very few models have been developed to date; however, their validation is still underway. It is expected that validated models play critical role for process optimization to reduce residual stresses, crack and pores formation.

Although AM has already produced some impressive results, reliability and repeatability are still significant problems, particularly for series production. Failure rates for many applications remain high, where the utilization of AM may not be economically justifiable. The underlying source of issue is that AM is so sensitive to both environmental and process disturbances. Complete controlling of processes and the environment is extremely challenging with the existing technologies and knowledge, so researchers are focused on the deployment of innovative sensors to monitor melt pool and other process conditions. Interpreting the monitoring data, quality control algorithms are developed to automatically adjust process parameters, such as laser power or process speed, to compensate for disturbances. One major issue for the monitoring and closed-loop control of AM processes is the size of data streaming from the sensors. For example, in a typical selective laser melting, known as powder-bed fusion, the process speed could reach 5 m/s. If a thermal camera and a few photodiodes monitor the process zone, the size of data stream could be around 7 GB/s. This size of data obviously falls under the online "big data" category that is extremely challenging to

In Canada, a strategic Pan-Canadian network entitled "Holistic Innovation in Additive Manufacturing (HI-AM) Network" was formed in late 2017 to address the above mentioned challenges. The network that is funded by Natural Sciences and Engineering Research Council (NSERC) and Canadian Foundation for Innovation (CFI) includes seven universities coast-to-coast. Led by the University of Wa-

#### MSAM lab is one of the largest academic R&D additive manufacturing facilities in the world.



DR. TOYSERKANI (FAR RIGHT) AND MSAM RESEARCHERS AND STAFF AT THE UNIVERSITY OF WATERLOO.

terloo, six other universities including McGill, UBC, Dalhousie, Toronto, Laval and Alberta as well as 14 companies, five international institutes and three government R&D partners are involved in this Network. The Network investigates fundamental scientific issues associated with AM pre-fabrication, fabrication, and post-fabrication processing. It is enabling collaboration between Canada's leading research groups in advanced materials processing and characterization, powder synthesis, alloy development, advanced process simulation and modeling, precision tool-path planning, controls sensing, and applications, with investigation in four parallel themes:

Theme 1: Material development tailored with optimum process parameters.

Theme 2: Advanced process modeling and coupled component/process design.

Theme 3: In-line monitoring/metrology and intelligent process control strategies.

Theme 4: Innovative AM processes and AMmade parts.

The overall goal of the HI-AM Network is to provide realistic, transferable solutions for the foremost challenges preventing industry from converting their conventional manufacturing methods into metal AM processes. Attaining this goal through HI-AM's research activities is securing Canadian leadership in the AM sector through enabling a more rapid adoption and commercialization of current, emerging and completely novel AM technologies, and by decreasing the timeframe for the translation of HI-AM innovations to Canadian industry through the AM parts produced with HI-AM's supply-chain partners. As well, HI-AM is creating an exceptional opportunity to train highly qualified personnel (HQP) in a growing, high-demand field through a collaborative, multidisciplinary research program, providing an active, innovative learning atmosphere. The

development, optimization and implementation of new materials/alloys, AM process models and simulation, monitoring sensors and closed-loop control systems and novel AM processes/products through the established partnership are resulting in intellectual property to be available to the Canadian Industry. Innovations developed through HI-AM will include innovative quality assurance algorithms, next generation AM processes, optimal process recipes for advanced materials adopted for AM processes, and closed-loop/intelligent AM processes.

Last but not least, HI-AM is fostering lasting relationships among partners from private to public sectors. HI-AM will emphasize strengthening collaborative interactions between academic researchers, the Canadian manufacturing industry, industrial organizations, government researchers, and international collaborators by addressing complex technical issues associated with metal AM.

- 1. Y. Huang, M.C. Leu, J. Mazumder, and A. Donmez, "Additive Manufacturing: Current State, Future Potential, Gaps and Needs, and Recommendations", ASME Journal of Manufacturing Science Engineering, 137(1): 014001, 2015.
- 2. J. Manyika, M. Chui, J. Bughin, R. Dobbs, P. Bisson, and A. Marrs, "Disruptive technologies: Advances that will transform life, business, and the global economy," McKinsey Companies, 2014.

ORLD-CLASS NON-DESTRUCTIVE TESTING (NDT)

FACILITIES, INCLUDING A NANO- COMPUTED TOMOGRAPHY (CT) SYSTEM, IN MSAM HAS ENABLED

WITH metal AM.

MSAM'S RESEARCHERS TO EFFECTIVELY GAIN INSIGHT TECHNOLOGICAL ISSUES OF AM PROCESSES.

MSAM'S RESEARCHERS TO EFFECTIVELY GAIN INSIGHT TECHNOLOGICAL ISSUES OF AM PROCESSES.



# REVOLUTIONIZING MARINE MANUFACTURING

#### Dr. MOHSEN MOHAMMADI, PhD

Dr. Mohammadi is an assistant professor of mechanical engineering and director of Marine Additive Manufacturing Centre of Excellence at the University of New Brunswick. He received a PhD from the University of Western Ontario. He then joined CanmetMATERIALS and University of Waterloo as a visiting scientist and postdoctoral fellow, respectively. Dr. Mohammadi's main areas of research are metal additive manufacturing, marine additive repair and the shipbuilding factory of the future. Dr. Mohammadi is leading significant projects in metal 3D printing for the marine, shipbuilding, and defence sectors. Among them is a \$12 million industrial initiative to adopt additive manufacturing in the next generations of Canada's warships in collaboration with Irving Shipbuilding Inc., J.D. Irving, Limited., Lockheed Martin, and Custom Fabricators & Machinists (a J.D. Irving, Limited Company). Dr. Mohammadi is developing advanced materials produced using metal additive manufacturing techniques. His current research focuses on enhancing the mechanical, corrosion, impact, and fatigue properties of additively manufactured metals (aluminum, titanium, steels). It also involves 3D printed long fibre composites, metal matrix coatings and ultra-light high strength metamaterials.

#### THROUGH THE SUPPORT OF OUR MANY

partners, our team has developed a technology that is poised to revolutionize the marine industry worldwide. The technology is additive manufacturing, also known as 3D printing. It's already used in the aerospace and medical industries and this disruptive technology is becoming much more efficient and appealing compared to traditional methods of manufacturing.

It is estimated that more than 90 per cent of global trade is carried by sea – tens of thousands of ships carrying millions of tonnes of goods, produce and materials. And that doesn't account for the ships that are used in the defence sector.

Additive manufacturing, as its name indicates, operates through successive material additions rather than removing or reshaping existing material. Wafer-thin layers of material are added to create a variety of shapes and strengths that would be impossible with traditional methods. Parts no longer need to be carved, cut or welded together but rather are created in one piece with no weak joints susceptible to stress. This is done using specialized computer software developed by our team and printers that are far cleaner and greener than traditional manufacturing methods

Through a partnership forged between the University of New Brunswick, Custom Fabricators & Machinists, and community colleges in New Brunswick and Nova Scotia, our ground-breaking technology was given a home last year with the establishment of the Marine Additive Manufacturing Centre of Excellence. Further, the New Brunswick Innovation Fund (i.e. NBIF) also played a key role in bringing this technology to the Maritimes.

The centre's mission is to ensure the adoption of this leading-edge technology in the Maritime provinces of Canada, by developing new methods, procedures and additive training programs. This unique initiative is enabling New Brunswick and Canada to develop core expertise in this emerging technology and help create the foundation for the next generation of manufacturing.



"The challenge for Canada's manufacturing industry is to stay current to ever-changing fabrication equipment and methods."

MAMCE AT THE UNIVERSITY OF NEW BRUNSWICK:

INDUSTRIAL PARTNERS.

MOHAMMADI (CENTRE), HIS RESEARCH GROUP AND

The challenge for Canada's manufacturing industry is to stay current to ever-changing fabrication equipment and methods. Much like the telecommunications industry, which has been transformed by advances in wireless technology, traditional fabricators and engineers now face the disruptive effects of additive manufacturing. The profitability and competitiveness of once popular and proven fabrication methods will decrease to the point of being unsustainable. To survive and prosper, industry must partner with those advancing this technology including the educational institutions that will train the next generation of workers.

The centre is the first in Canada to develop 3D metal printing as a method for manufacturing certified parts for the marine industry. The work being done at the centre is revolutionizing the way ships are made and has the potential for saving industry millions of dollars.

Additive manufacturing, using 3D metal printing, is simplifying supply chains, providing complicated parts on demand and enabling the fabrication of new components by Canadian fabricators.

The centre is also the first of its kind in Canada to combine the three pillars of research, workforce training, and commercialization. My team and I are leading the research portion.

Workforce development and training pillar is being led by the New Brunswick and Nova Scotia community colleges. Additive manufacturing courses are enhanced by the opportunity to work hands-on with the centre's powder bed 3D metal printers. Certificate programs have been developed to provide the current workforce exposure and training on the equipment.

The third and final pillar is the commercialization of the technology through integration with the fabrication and manufacturing sector. We have engaged a director of commercialization, through CFM, whose focus is on business development. To assist the business community in adapting to new technology, participants may use the support of the centre to gain knowledge and exposure to additive manufacturing. With effective partnerships, proven research techniques, and workforce development; we are securing successful adoption of additive manufacturing for fabrication in Canada.

The multi-million-dollar centre was initially funded by Lockheed Martin Aeronautics and Irving Shipbuilding Inc. We are currently seeking more industry participants with an active interest in marine and defence manufacturing and partners capable of bringing experience in additive manufacturing in other sectors willing to participate in field trials and commercialization projects.

Our current members and partners have priority access to our vast collection of research, field additive manufacturing experts, the opportunity to leverage funding through IRB/ITB credits and the potential for contract research projects.

We're seeing increasing numbers of leading research professionals and organizations are showing interest in coming to New Brunswick to be part of what we're doing. Our technology is greener and more efficient than conventional methods and will create high-value jobs here in Atlantic Canada. I'm so grateful to our many commercialization, industry and training partners who have supported our work so far and I look forward to welcoming new participants in the future.

Students interested in joining the University of New Brunswick to become part of the program can also consult the website (unb.ca/mamce) to determine whether their expertise might be compatible with our research portfolio. Industry and commercial interest are also welcome to contact the centre through the website (unb.ca/mamce).

# UNLOCK THE POTENTIAL OF Additive Manufacturing

EXAMPLES OF MESOSCALE LATTICE STRUCTURE (IMAGE BELOW AND TOP RIGHT)





DR. YAOYAO FIONA ZHAO, PhD

Dr. Zhao is currently an Assistant Professor and the head of the Additive Design and Manufacturing Laboratory (ADML) at the Department of Mechanical Engineering in McGill University. Her research expertise lies in the general field of design and manufacturing including the exploration of new design methods, manufacturing informatics, sustainable product development and intelligent manufacturing. Her team is leading the research in Design for Additive Manufacturing with the development of new design methods to achieve multi-functionalities, less part count, better performance and better sustainability performance.

ADDITIVE MANUFACTURING (AM) IS A manufacturing technique that fabricates parts directly from a 3D model typically adding materials at desired place layer-by-layer. AM technology, compared to the conventional manufacturing methods such as subtractive machining processes, moulding processes, casting processes, etc., has tremendous potential for producing high-value, complex, individually customized parts. Parts made of heterogeneous materials with varying material properties and functional gradients can be fabricated using AM technology with relative ease. The capability of AM greatly enhances freedom for designers to explore novel engineered products for a variety of new applications. Multiple functions can be integrated in fewer assembly components, which results in less logistical effort and greater flexibility. In fact, AM technologies have created

a new paradigm in manufacturing by enabling

the creation of cost effective high value products.

However, there is no valid design method to encourage function integration at early design stage. Function integration means implementing as many technical functions as possible into as few parts as possible. The process to re-design an assembly to achieve function integration is often referred as part consolidation. Most existing AM-enabled part consolidation examples were individual case studies conducted by industry to investigate the design potential enabled by AM technology. There is lack of a systematic approach for part consolidation. Moreover, existing geometric modeling methods, such as parametric boundary representation or solid modeling techniques developed to represent relatively simple geometries for conventional manufacturing processes, are no longer capable to represent sufficient information for AM design. They need to evolve in order to better represent complex geometries, multiple materials, material property gradients, and multifunctional concepts. To support function integration at early design stage and the designing of complex heterogenous structures for multi-functionalities, simulation tools, such as topology optimization software, are needed at early design stage. In order to unlock the true potential of AM technology, we need to overcome the bottleneck of existing design methods and tools.

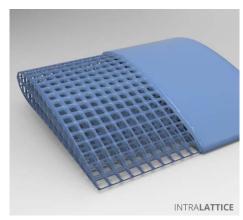
Professor **Yaoyao Fiona Zhao** and her research team in the Department of Mechanical



Engineering at McGill University is leading the effort to develop novel design methods and tools to support next generation product design for AM technology. More specifically, her team focuses on the following design approaches: multiscale and multifunctional design method for mesoscale lattice structures, functionality-driven design method for part consolidation at conceptual design stage, and design ideation support tool for AM. To support these design methods, a number of simulation methods and tools are also developed such as mesoscale lattice simulation tool and AM manufacturability checker. Her students are also developing efficient numerical tools to simulate Laser Powder Bed Fusion (LPBF) and Direct Energy Deposition (DED) AM processes. The innovative lattice design, simulation and optimization software developed at ADML named as INTRALATTICE has been released for public downloading since August 2015. It has been downloaded over 7000 times all over the world by almost all major 3D printing companies and research facilities. A new version of the software called INTRALATTICE Prowill be available soon with enhanced modeling. simulation and optimization capabilities.

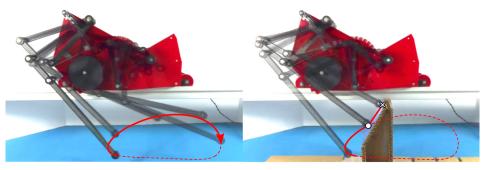
At McGill University, there are over 25 researchers and their teams spanning over 7 faculties including Engineering, Science, Dentistry, Medicine, Music, Desautel Faculty of Management and Arts are actively conducting fundamental research related to AM technology. With such extensive efforts, researchers at McGill University hope to unlock the true potentials of AM technology and benefit Canadian society.

HETEROGENOUS LATTICE INFILL IN THE WING OF UVA



#### **ME NEWS & RESEARCH**

# HIGHLIGHTS



a) Freespace trajectory

a) Trajectory with obstacle

# Towards Improved Walking Robots

CSME Transactions — Journal Editor's Choice

Legged robots have strategic advantages for use in rough terrain. Current robot legs often require several actuators to be appropriately maneuvered. A team of researchers from the École Polytechnique, Montréal, consisting of Dmitri Fedorov and Lionel Birglen, are developing a mechanism that can enable a simplified under-actuated robotic leg to be driven using only one actuator. The leg is inspired by self-adaptive mechanisms which were developed for use in robotic hands. The mechanism transfers the actuation via a number of flanges to actuate the entire mechanism. The flanges are automatically configured using a preloaded spring and mechanical limits to change the distribution of the force from the actuator depending on the external forces acting on the leg. Recently, the team has also been determining the optimum setup to enable the leg to adapt to colliding obstacles during different phases of its operation. "Reducing the electronic complexity (i.e. sensors, controllers) of a robotic system can provide benefits for applications where harsh conditions affect the reliability of electronic components," explained the authors.

— Technical Editor, Professor Amy Bilton

D. FEDOROV, AND L. BIRGLEN, "GEOMETRIC OPTIMIZATION OF A SELF-ADAPTIVE ROBOTIC LEG," TRANSACTIONS OF THE CANADIAN SOCIETY FOR MECHANICAL ENGINEERING, APRIL 2018.



# If it's broke, it can fix itself

A new class of materials, currently being developed, can actually mold themselves back together after being broken. These materials, called self-healing materials, have broad applications in coatings, epoxies, medical devices, and sensors. A team at the University of Manitoba, led by Malcolm Xing and Goaxing Luo, have recently developed a conductive self-healing hydrogel. The hydrogel can be 3-D printed and is ultra-stretchable, with extensions up to 1500%. The hydrogel is able to self-heal due to the ionic interactions between carboxylic groups of acrylic acid and ferric ions. After being broken, the hydrogel self-heals to recover 90% of its electrical conductivity in less than 30 seconds and 100% of its mechanical strength within two minutes. The research team is currently engineering the material to make 3D printed electric skin which will serve as a heart patch for monitoring and repairing cardiac tissue after a myocardial infarction. - Technical Editor, Professor Amy Bilton

M. A. DURABI, A. KHOSROZADEH, R. MBELECK, Y. LIU, Q. CHANG, J. JIANG, J. CAI, Q. WANG, G. LUO, AND M. XING, "SKIN-INSPIRED MULTIFUNCTIONAL AUTONOMIC-INTRINSIC CONDUCTIVE SELF-HEALING HYDROGELS WITH PRESSURE SENSITIVITY, STRETCHABILITY, AND 3D PRINTABILITY," ADVANCED MATERIALS, VOL 29, ISSUE 31, AUGUST 2017.

Interested in Canadian ME advances by exploring scientific publications?

Join the CSME Bulletin as Technical Editor

Contact the editor prezai@yorku.ca with expressions of interest.



#### **CSME STUDENT CHAPTER**

# REPORT

CSME STUDENT CHAPTERS ACROSS THE country have been organizing events to engage current undergraduate students in industry networking events, design competitions and industry guest lectures. We have also seen an increased engagement in the student membership at CSME with the introduction of FREE student membership. The new EngineeringCareers.ca site also provides students an opportunity to plan ahead for their careers. Several new CSME student chapters were recently founded including at the University of Guelph and the University of Ottawa. New chapters are also in the process of

Many exciting chapter activities and events were held this past year. Here are a few highlights:

forming at several other institutions.

At the CSME **UBC Okanagan** student chapter, their biggest event was the 3rd annual quadcopter competition. Five teams competed to design, build and test a mini-quadcopter with limited resources in only 3 hours. Teams competed to fly their quadcopter through the obstacle course (through hula hoops and popping balloons). Teams were judged on the quadcopter design and flying capabilities.

At the CSME **University of Guelph** chapter, they held an industry talk by Dr. **Faizul Mohee**, P.Eng. with over 35 participants. He gave an engaging presentation on his research and industry experiences. He also shared some samples that facilitated visualizing and grasping the new concepts. A Q&A session also helped students gain more insight on the reality of a workplace and provided them the opportunity to ask more targeted questions.

The CSME **uOttawa** chapter co-organized a Green Curriculum, Campus, Community event which was a full-day of interactive sessions, panels and guest speakers. uOttawa also organized a second event on Greening Design and Entrepreneurship which included a guest lecture by **Mark Pearson** from the Technology Transfer Office at uOttawa and an exhibition of fifty mechatronics student projects.

The CSME Western University chapter organized a panel session where current Internship/co-op students shared their thoughts and experiences through the whole recruitment process. An open Q&A and networking session provided students an opportunity to ask about specific tips and tricks and advice on resume and cover letters.

At the CSME **BCIT** chapter, they kicked-off the year with a Welcome BBQ for first year stu-

dents. Students met and mingled with their fellow classmates, upper year students and faculty. BCIT also hosted an inaugural industry-student night with 15 companies and 200 attendees in total. BCIT had a social gathering Go-Karting too.

Overall, there were many great events this past year. Chapters did a great job encouraging students to participate in the CSME National Design Competition and registering as CSME student members.

Thank you to all the student chapter executives, volunteers and faculty mentors for your hard work! We look forward to supporting and hearing about your next chapter activities!

If you're interested in leading the founding of a CSME student chapter at your campus, let us know, we will walk you through the process. Do you have a great idea, story or proposal to improve the CSME student programming? Please feel free to reach out with your feedback!

#### CSME UNIVERSITY OF GUELPH STUDENT CHAPTER INDUSTRY SPEAKER EVENT (LEFT TO RIGHT): MISHA

SINGH NATH (VP), MUHAMMAD IBRAHIM (TREASURER), MOHAMED ALY (PRESIDENT), DR. MOHEE, OLUWADUNSIN "SEUN" AGBETUYI (COMMUNITY RELATIONS), BRIAN NGUYEN (WEBMASTER) AND JOSEPH LEE (SOCIAL CHAIR).



CSME BCIT STUDENT CHAPTER INDUSTRY NIGHT





#### CSME UBC OKANAGAN STUDENT CHAPTER

EXECUTIVES (TOP ROW) MATTHEW BARRIAULT (GRAD REP), JANNAT BACHHAL (EVENTS COORDINATOR), JESSICA REMPEL (PRESIDENT); (FRONT ROW) CALLEM MCDOUGALL (3RD-YR REP), ZACK PFOB (TREASURER), MAX LAURETA (VP), EVANGALINE SACLAMACIS (NEXT VP) AND HANNAH GOMES (SECRETARY).



#### CSME uOTTAWA STUDENT CHAPTER

EXECUTIVES (TOP ROW) SUZANA VUKOVC (COMMUNITY OUTREACH MANAGER), AMRO AHMED (CO-PRESIDENT), JENNY LANG (OUTREACH/EXTERNAL), (SECOND ROW) MATT SEHRI (CO-PRESIDENT), ASHAR QURESHI (UG REPRESENATIVE), AMINE MJIDOU (VP) AND ZAINAB BADAWI (SECRETARY).



#### DR. MARINA FREIRE-GORMALY, PhD, EIT, SCMSE

Chair of CSME Student Affairs

Marina recently completed her PhD at the University of Toronto in the Department of Mechanical and Industrial Engineering on the Experimental Characterization and Design of Solar Powered Water Treatment Systems. She is currently a post-doctoral fellow at the University of Toronto. Marina is passionate about research, teaching and student engagement to tackle society's most pressing energy and water challenges.



**NEW FACULTY SPOTLIGHT SERIES:** 

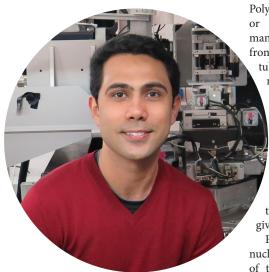
# FOCUS ON CENTRAL CANADA

This series highlights new Canadian ME faculty members by region. In this issue, we focus on central research highlights from:

Dr. Hamidreza Abdolvand, Western University Dr. Amirkianoosh Kiani, University of Ontario Institute of Technology Concordia University's Dr. Tsz Ho Kwok and Dr. Brian Vermeire

# Western University Dr. **Hamidreza Abdolvand**

### Deformation of Polycrystals: new techniques for solving multifaceted problems



#### Dr. **HAMIDREZA ABDOLVAND**, PhD

Hamidreza Abdolvand is an Assistant Professor in the Department of Mechanical & Materials Engineering, at Western University. His research focuses on deformation of engineering materials across scales. Advanced diffraction, imaging, and finite element modelling are the three main toolboxes that have been developed in his group.

Before joining Western, he was a postdoctoral researcher at the University of Oxford where he worked on electron and synchrotron X-ray diffraction analysis of engineering materials. Prior to Oxford, he worked at the University of Manchester, developing finite element codes for Rolls-Royce and AMEC-Europe.

Hamid received his PhD in 2012 from Queen's University, Canada, where he developed a crystal plasticity finite element code for modelling deformation of polycrystalline materials such as zirconium, steel, or magnesium alloys.

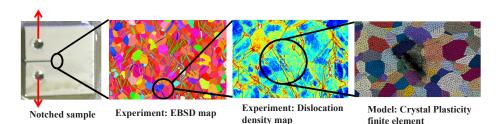
Polycrystalline materials, such as titanium or zirconium alloys, are vastly used in manufacturing of engineering components, from blade of a jet engine to nuclear pressure tubes. At microscopic levels, they are all

made of grains that have unique mechanical properties. Depending on how grains are configured in a polycrystal and how they interact to accommodate an applied load, the life-span of an engineering component can vary. As such, for a given polycrystalline material, it is possible to come up with an intelligent manufacturing process, or modify the existing ones, such that the performance of the component for a given purpose can be improved.

For example, the life-span of thick-walled nuclear pressure vessels depends on the state of the residual stresses that develop during welding. At the vicinity of thick-section welds, macroscopic stresses can build up and alter atomic distances. Such stress concentration sites are prone to stress-assisted corrosion cracking or to embrittlement due to hydrogen diffusion. SA508 grade 3 and grade 4 are nuclear pressure vessel steels that undergo phase transformation during welding. Depending on the welding parameters, such as torch speed or input energy, different phases with different level of stresses can develop in these materials. Also, it is often impractical or costly to measure state of residual stresses in thick welds. For such cases, it is important to have validated finite element codes that can provide accurate estimation of the level of residual stresses. Dr. Abdolvand has developed a series of finite element codes for optimizing weld parameters to mitigate residual stresses while optimizing the resulting material microstructure. This is to improve the performance and increase the life-span of nuclear pressure vessels.

At micro-scale, the mismatch between elastic and plastic properties of grains in a polycrystal can lead to localized stress fields that can turn into crack nucleation sites. Controlling such stress fields can help controlling the nucleation of cracks and hence, improving life-spans of engineering components. The challenge, however, is in measuring state of the stresses or developing numerical toolboxes that not only can replicate macroscopic behaviour of the engineering component, but also can provide sensible insight toward localized stress fields. In Dr. Abdolvand's group, synchrotron X-ray and high resolution electron backscatter diffraction (HR-EBSD) techniques are being used to measure such localized stress field. While with high energy X-ray it is possible to measure internal stresses in three-dimension at microlevels (~µm), electron diffraction can provide a much higher spatial resolution (~nm) in the expense of losing sub-surface information. These experimental techniques can provide invaluable data for calibrating or validating predictive finite element models.

For example, in an attempt to understand fundamentals of deformation in zirconium and titanium alloys, Dr. Abdolvand has used threedimensional synchrotron X-ray diffraction for in-situ measurement of grain level stress tensors in more than 15000 grains. The measured micro-structures were then imported into a finite element model to simulate their deformation mechanisms. The results of this study indicate that while macroscopic stresses increase, grain-level stresses can relax as a result of the local neighbourhood and load sharing between hard and soft grains. This is significant as such load-sharing controls the process of hydrogen diffusion in the zirconium alloys used in nuclear industry. Diffusion of hydrogen into zirconium crystals can reduce the fracture toughness of zirconium alloys and cause safety issues. Similarly, load sharing between grains of titanium alloys used in aerospace industry, can control their fatigue life. The results of this research is published in *Nature communications*, Vol 9, no. 171.



# University of Ontario Institute of Technology Dr. **Amirkianoosh Kiani**

### 3D Nanofibrous Materials: Significance in Advanced Manufacturing



Dr. AMIRKIANOOSH KIANI, PhD. P.Eng.

Dr. Kiani is an assistant professor in the Department of Automotive, Mechanical and Manufacturing Engineering (AMME) at UOIT. He obtained his Master of Science degree in Mechanical Engineering from the National Technical University of Ukraine, and his PhD in Mechanical Engineering from Ryerson University, Canada. Prior to joining the UOIT, he worked as an assistant professor in the Department of Mechanical Engineering, University of New Brunswick (UNB). He joined the UOIT in July 2017, where he established his current research facility named Silicon Hall, which is focused on advanced materials processing and micro/nano manufacturing. Dr. Kiani's core research addresses challenges in the fundamental and applied research in the area of pulsed-laser materials processing in laser micro/nano manufacturing.

3D Nanofibrous materials: Nanofabrication using laser pulses offers unique advantages over other approaches. It is single-step and can be applied to a wide range of materials. Dr. Kiani's current research in short laser pulse nanofabrication has demonstrated that the pulsed ultrashort laser ablation technique is capable of preparing nanofibre-coated substrates which are immediately usable in different applications such as advanced engineering materials and bio-functional materials.

Dr. Kiani's previous research on laser micro/nano fabrication has established the groundwork for nano material processing using ultra-short laser pulses. This technique also opens up the possibility of generating nanostructures, such as 3D nanofibrous structures, nano-composites, and nanoalloys, which are difficult to synthesize by any other means. His current work will take a leap forward by demonstrating a new 3D nanohybrid material and thin-film-based substrate that can be used in a wide variety of applications such as biosensor, biomaterials, and biomedical device fabrication.

Funded in partially by the National Science and Engineering Research Council of Canada (NSERC) and the Ontario Centre of Excellence (OCE), Dr. Kiani has initiated a new project in collaboration with Kennedy Labs for synthesis of 3D porous structures on silicon. "In this

project, in collaboration with Dr. Kiani, we focus on infusing porous silicon with graphene and other metals to control its physical and chemical properties for creating new sub-components for our industrial customers. "We had very good progress in the short period and samples of the porous silicon at various densities, depths and sizes have been successfully produced and are available at Digi-Key," explained Brian Kennedy, company President.

Silicon wafers are irradiated by a laser beam at different pulse repetitions and durations to generate a 3D nanofibrous thin-film on the substrate with a different porosity and thickness. The 3D nanofibres generated by the laser pulses have diameters ranging from 10 to 100 nm. In the next step, the graphene, reduced graphene oxide (rGO), and/or metallic nanoparticles (NPs) of gold are coated on laser-treated samples by sputtering technique or Atomic Layer Deposition (ALD) methods. The type of NPs as well as their concentration and average size can control the physical and electrical properties of the generated nanostructures for different applications such as sensor, capacitor, and energy storage devices.

Creating 3D nano structures on silicon, or building them up on top of silicon, can be a costly exercise using conventional methods. In Dr. Kiani's proposed method for laser nanofabrication, a thin film or predetermined high-resolution patterns of 3D nanofibrous structures can be synthesized under room conditions at extremely rapid speeds with high precision and repeatability. "As consumer, medical, space and industrial applications continue to shrink but demand higher levels of performance and lower costs, porous silicon based devices can offer a solution. This can be done quickly without costly masks and using existing equipment technology, and scaled up into production," said Dr. Dolf Landheer, Kennedy Labs' Chief Scientist.

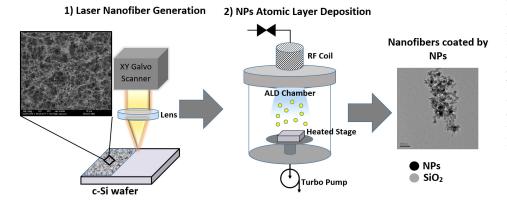


FIG. 1. FABRICATION METHOD AND EXPERIMENTAL SETUP

# Concordia University Dr. **Tsz Ho Kwok**

#### Additive Manufacturing and Mass Customization



Dr. TSZ HO KWOK, PhD, MCSME

Dr. Kwok is an Assistant Professor in the Department of Mechanical, Industrial and Aerospace Engineering at the Concordia University, Montreal, Canada. Before joining Concordia, he was a Postdoctoral Research Associate in the Epstein Department of Industrial and Systems Engineering at the University of Southern California. He received his Ph.D. degree in the Department of Mechanical and Automation Engineering from the Chinese University of Hong Kong. His research interests include 3D printing, design for additive manufacturing, functional design and fabrication, cyber-manufacturing system, and mass customization. Dr. Kwok has received several awards including the 8th Chinese Youth Science and Technology Innovation Prize, the Microsoft Research Fellowship Nomination Award, and the CUHK Postgraduate Research Output Award. He serves as an Associate Editor in the Transactions of the Canadian Society for Mechanical Engineering (TCSME). His academic page can be found by goo.gl/HhWbC.

Additive manufacturing (AM) can fabricate parts directly from Computer-Aided Design (CAD) models without part-specific tools or fixtures. This promising approach is changing the nature of manufacturing in product design and fabrication. One attractive capability of AM is that it can produce custom products without increasing time, material or cost, which offers complexity for free. Custom products have inherent advantages over their mass-produced counterparts. They can provide more comfort, unique feature, and better performance. One of Dr. Kwok's research goals is to enhance the current fundamental knowledge regarding the necessary design and manufacturing techniques to evolve the mass production to mass customization. At the core of the AM technology are three key components: process, material and design. To utilize the capability of AM and realize mass customization, the research and development of these three key components need to be connected and synchronized. Therefore, Dr. Kwok has defined four main research programs to study and leverage the geometric and material freedoms of AM.

#### **Product Design and Customization**

Traditional CAD software is not developed for 3D printing and can hardly customize product on freeform surfaces. Dr. Kwok developed a new platform (DesignForFab) for the designs of 2-manifold surfaces. A set of fabrication tools like thickening and widening is included to support 3D printing. Another design tool (Cross-parameterization) to enable the reuse of information among models and generative design is also developed. Both design tools are made available online.

#### Design for Additive Manufacturing (DfAM)

Design for manufacturing concerns mainly on constraints, but DfAM explores complexity to achieve superior performance. One example in structural design is to minimize the weight and at the same time maximize the stiffness of a structure. This is the topology optimization problem, which is computational expensive. Dr. Kwok developed a set of design guidelines and convert the optimization to a geometric design problem based on Principal Stress Line (PSL),

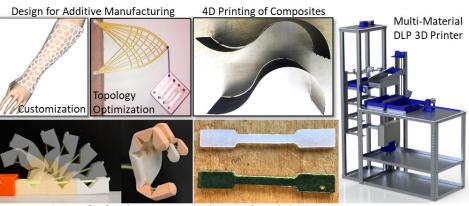
which has an interactive design speed and is more practical. Dr. Kwok has also worked in multi-material design, adaptive slicing, and internal filling pattern.

#### **Functional Design and Fabrication**

The current layer-based AM process has drawbacks such as slow fabrication speed and poor surface finishing. Dr. Kwok is working on 4D printing (3D printing + time) which creates smart structures that are shell-like, lightweight, and can be self-shaping, folding, or assembly. The printed materials are designed to self-deform their shapes in a pre-defined way. It has been applied to various polymers, composites, and elastomers. Dr. Kwok has also developed Geometry-Driven Finite Element (GDFE) to simulate this kind of sophisticated and large deformation in real time.

#### **Cyber-Manufacturing**

To complete more challenging fabrication tasks, machines need to be smarter. They should have the capability to deal with the environment and complicate operations. Dr. Kwok has worked on process monitoring and control systems, automation, robotics systems, self-optimize systems, and sensing systems. He has developed a new multi-material 3D printer using DLP technology, which is the first in Canada. He has also developed an in-situ process correction system to improve the jetting behavior of metal 3D printing.



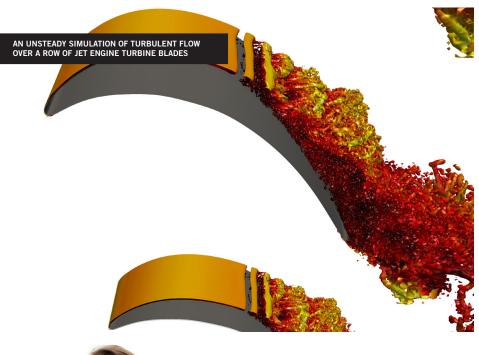
3D Printing of Soft Robotics

Fiber-Reinforced Elastomer

RESEARCH ACTIVITIES IN THE THREE KEY COMPONENTS OF ADDITIVE MANUFACTURING: DESIGN, MATERIAL AND PROCESS

# Concordia University Dr. **Brian Vermeire**

#### A New Generation of Computer Models for Green Aviation





Dr. BRIAN VERMEIRE, PhD, MRAeS, CEng

Dr. Brian Vermeire, has been an Assistant Professor in the Department of Mechanical, Industrial, and Aerospace Engineering at Concordia University since 2016. Prior to joining Concordia, he was a Postdoctoral Associate in the Department of Aeronautics at Imperial College London. He received his PhD in Mechanical Engineering from McGill University in 2014 and MASc and BESc degrees in Mechanical and Materials Engineering from Western University in 2008 and 2010, respectively. He previously held research positions at Cambridge University and Central Michigan University. Dr. Vermeire is currently the head of the Concordia Computational Aerodynamics Laboratory. His research group is working on the development of novel computer models to design of the next generation of cleaner and quieter aircraft.

Over the last century, aviation has widened international frontiers for business and leisure travel. According to the International Civil Aviation Organization (ICAO), passenger aircraft moved an astonishing 4.1 billion passengers in 2017. However, the growth of civil aviation has significantly increased greenhouse gas emissions (GHG) and noise pollution near airports. Reducing aviation-related emissions and noise pollution is the focus of several national and international research projects on green aviation. Dr. Brian Vermeire's research as head of the Concordia Computational Aerodynamics Laboratory contributes to reducing the environmental impacts of aviation. His team is working on the development of a new generation of computer models that will enable engineers to design cleaner and quieter aircraft, and provide insights into the complex physics of aerodynamics.

Since the 1960's aircraft designers have increasingly relied on Computational Fluid Dynamics (CFD) as a tool for aircraft design. Often referred to as a numerical wind tunnel, these tools use computers to find approximate solutions to the complex physics of air passing over aircraft wings, control surfaces, engines, and other components. This approach has increased in popularity in recent years due to its low cost

relative to experiments and flight testing. However, current generation computer models used by industry have limited accuracy. These models are primarily useful for finding time averaged flows, but neglect the true unsteady chaotic nature of turbulent aerodynamics. This limits their accuracy and the range of applications to which they can be applied. As a result, aircraft designers need a new generation of CFD tools that capture unsteady turbulent flows and more accurately predict aircraft performance.

Dr. Vermeire's work on CFD sits at the intersection of physics, mathematics, computer science, and engineering. His team is developing novel models that convert the mathematical problem of aerodynamics into one that can be solved efficiently using modern computers. His recent work has shown that these models can be both an order of magnitude faster and more accurate than industry standard tools, and capture the true unsteady nature of aerodynamics. Furthermore, these models can efficiently use modern many-core hardware architectures, such as Graphical Processing Units (GPUs), which are significantly more powerful than traditional Central Processing Unit (CPU) based supercomputers. Transitioning to these GPU-based systems is important for the aviation industry, as their computing power allows for more accurate simulations to be performed in less time.

Working with collaborators at Imperial College London, Dr. Vermeire's work in this field has received international recognition. His contributions to the open-source CFD package PyFR was shortlisted for the Gordon Bell Prize, which recognizes extraordinary achievement in the field of computational sciences and engineering. This arose from collaborative simulations of jet engine low-pressure turbines on Titan, the largest supercomputer in the United States. The majority of the software developed by Dr. Vermeire and his lab is released free and open-source. His current work focuses on reducing the cost of CFD simulations, increasing their accuracy for unsteady flows, and creating novel optimization approaches to exploit these simulations for aircraft design.





#### Dr. TONYA WOLFE, PhD, P.Eng.

Dr. Wolfe is a senior metallurgical engineer at InnoTech Alberta, Edmonton, Canada. Her areas of expertise include welding of overlays, wear resistant materials, metallurgical characterization, process design, and infrared thermography. She attended Queen's University for her Bachelor of Applied Science in Metallurgical Engineering, and after a few years as a steelmaking process engineer, decided to pursue her graduate degrees at the University of Alberta. Her MSc investigated the use of smart materials as prosthetic ocular actuators and her PhD studied the homogeneity of metal matrix composites deposited by plasma transferred arc welding. She is also an adjunct professor and sessional instructor at the University of Alberta.

### What got you interested in the field of Additive Manufacturing (AM)?

AM is a tool that will enable us to design for feature rather design for manufacturing. It's exciting to have a methodology that will enable us to become more sophisticated and innovative designers. It is a holistic approach that requires cross-functional teamwork. The relationship between designer, manufacturer and user is disrupted and strengthened because of the complexity of the process.

# Where do you think the field of Additive Manufacturing is heading in Canada in the next 10 years?

If we don't act soon, nowhere! Other countries are investing heavily in AM – China just invested \$330M on AM innovation centres, with another \$4B proposed, and have stated they have revenues of \$100M between 70 companies. Australia spent \$59M in 2017. UK has similar ambitions. Canada is fragmented and does not have the same level of investment. However, we should take pride in our strengths in the resource sector and find more efficient solutions using AM tools.

## How do you think Additive Manufacturing can help the mining and energy industries in Canada?

Industrial manufacturing, plant engineering, and machinery would absolutely benefit from AM. With the large scales involved, improvements in heat transfer efficiency, mass reduction, improved mixing or chemical reactions would be a benefit. Repair of critical components would also be beneficial. Components could also be tailored to have multi-materials, so they would have benefit from, for example, better wear and strength.

# Did you find any female role models in the manufacturing industry? In your opinion, how could we attract more female researchers to the manufacturing industry and to the mechanical engineering field in general?

Unfortunately, I have yet to find a female role model in manufacturing. I was really expecting more women to be attracted to additive manufacturing – it is new, challenges us to think in new ways, endless possibilities! However, I haven't seen that at the various conferences I have attended. There are women in graduate studies, but those numbers aren't translating to industry and academia. Why? It is very challenging to raise children and start your career. Many ca-

reers don't have an option to have a meaningful home life. For example – SpaceX and Tesla were advertising for new hires at a conference I was just attending and were saying "Want to work 16 hour days, every day, and be a part of the team that goes to Mars?" Who can do that and have a family? It's just not possible. It's also not fair to the young men who are leaving their children and partners at home. These great opportunities all come with a cost.

# What are the advantages of metal Additive Manufacturing compared to the more traditional methods used in manufacturing?

To me, AM is just a tool that allows us to start solving problems in a way we haven't before. Once we start designing for function, instead of manufacturing path, we open up a new realm of possibilities. That is our true advantage how we think and solve problems. We have to work together as a multi-disciplinary team to solve problems and it disrupts the flow of ideas from designer to end user. It's an elegant prospect (and may excite more women!) to work in cross-functional teams to make things that were once thought impossible to make. Our young engineers will stop being told "You can't do it that way", and instead will be asked "What improvements do you predict when it is made that way?" Simulations and modeling are the critical tools. Contrary to the media's messages, AM will not take over the world, but will just be another processing option. Software and modelling will take over the world! Adoption is still slow - but that's another topic for another day.

You are currently working on developing a partnership between academia, research institutes and manufacturers in the area of additive manufacturing in Alberta. What are the biggest challenges in order to establish academia - research laboratory collaborations? What about research laboratories - industry collaborations?

There are several reasons why AM has not been adopted in Alberta. The largest ones are: lack of capital for equipment, lack of trained people, and uncertainty of material properties. A partnership between academia-government-industry will solve those problems! In all cases, the biggest challenges are developing an equitable (and sustainable) funding model and building trust between partners. Industry wants the best solutions to enable them to be globally competitive. We need to support them as a cohesive team, and build on our strengths rather than duplication of efforts. I think we are getting there!

#### What are the major limitations for AM?

Major limitations are that we don't fully understand the physics of the materials – it is very complicated and complex. The solutions are coming, but are computationally expensive. In addition, the cost of the materials needs to come down – hopefully in time this will happen. You can see the number of new systems being developed with standard consumables – this is a great start to making the process more accessible. Lastly, people need to know that an AM part doesn't just get made by the push of a button. When you submit a drawing, it may take a day for the AM engineer to make it suitable for printing. There are many failed prints. This is not a technology that everyone can have in their home.

### What new AM technologies, such as levitating objects, do you envision in the future?

In the near future, we need multiple heat sources and multiple axis to deposit simultaneously. Processing with light is certainly the future. This will be challenging for certain applications! Faster build speeds, better feedback control (and predictive simulations) and larger builds are the focus in the next 5 years.

I have noticed that you have taught several design courses at the University of Alberta, do you think AM should be taught in the undergraduate curriculum? Do you have any suggestions on how to best integrate with the undergraduate curriculum?

Absolutely! AM should be taught in high schools! AM allows for creativity and ideation. Students learn what works and what doesn't – it's great for hands-on learners. We need to start teaching design as a cross functional team as well. At the start, before their knowledge of physics (and chemistry) is fully understood, they can understand what makes a good print. Later, they can apply their knowledge to design a part to achieve the 'optimal' results, then select a manufacturing route. I'd also like to see AM as part of an entrepreneurial course, where they can make small 'things', with support of a business plan, and see what profit they can achieve. This is what many engineers do all day in practice!

...continued from page 5

because no one has to tell us that we need to work hard". I would take it a step further, and say that many of us even feel the need to work too hard; it is not uncommon to see some of our young energetic Assistant professors routinely work late into the evening multiple nights weekly, and on the weekends. I won't need to remind most of the readers of the centuries old "all work and no play" proverb, perhaps most famously brought to popular culture in the 1980 film The Shining. But it appears to be lost on those who fear that if they don't spend every waking hour working productively, pushing constantly to stay ahead of their neighbours and colleagues (as if that somehow matters), writing more papers, bringing in more grants, receiving higher teaching evaluations, and on and on, then they won't be granted tenure. On one hand, I applaud the achievements of our current cohort of assistant professors. They are world-class professors in every respect, and their motivation and their accomplishments far exceed what I recall mine to be when I started my career just a short time before. The future success of our institution will be built on their shoulders. But on the other hand, my advice to them is that if you feel like you need to do work that hard, through late nights and weekends, "all work and no play", in order to be granted tenure, then maybe you've misjudged the height of the bar or what you need to do to get over it. I want and expect that every one of our hires will receive tenure, but also expect that in doing so, they will maintain a sustainable balance between work and, well, non-work.

As we progress through our current recruitment process, and our newly hired faculty members begin their careers, it will be critical to instill within them the same collegiality and desire for collaboration already shared by our colleagues, while encouraging them to strike a work-life balance that works for them. To quote my counterpart in another of our engineering departments (and which we've borrowed for our current position postings): "Our people are and will continue to be our greatest strength. We recognize the importance of academic excellence in conjunction with work/life balance, interdisciplinary collaborative research, mentorship, and a collegial atmosphere. We encourage individuals to strive for excellence in accordance with their abilities while maintaining a level of balance between teaching, research, and service to the university and the engineering profession. We celebrate creativity, diversity, perseverance, and a cooperative spirit." It is these values that I wish to promote and foster among our colleagues, current and future.



PRESENTATION BY DR. ROLF WÜTHRICH (CO-DIRECTOR CENTRE FOR ADVANCED MANUFACTURING) ON THE IMPORTANCE OF DEVELOPING FLEXIBLE MANUFACTURING TECHNOLOGIES TO MEET THE DEMANDS OF INDUSTRY 4.0.

#### SUMMER SCHOOL AT CONCORDIA UNIVERSITY:

Meeting the demand of the fourth industrial revolution



PARTICIPANTS GETTING HANDS-ON EXPERIENCE ON A CYBER-PHYSICAL SYSTEM (FESTO DIDACTIC CP LAB) DURING THE SUMMER SCHOOL.

#### LAST SUMMER, THE CONCORDIA INSTITUTE OF

Aerospace Design and Innovation (CIADI) and the Research Center on Advanced Manufacturing (CAM) offered a three-day summer school "Meeting the demand of the fourth industrial revolution," which focused on the challenges and solutions to prepare industry and academia for the advent of Industry 4.0. Industry 4.0 is the digitization of a company's physical assets and the company's integration into digital ecosystems with its value chain partners, from suppliers to customers. It uses smart technology and the use of real-time data to increase flexibility, customization, efficiency and productivity, and to reduce time, costs and innovation cycles.

Through renowned speakers, a full day hands-on workshop offered by Festo Didactic, research lab visits, and a networking cocktail and dinner, the Summer School was an excellent opportunity to advance technical skills, network, and interact with industry partners. Participants who successfully completed the program were granted a certificate attesting to the successful completion.

#### **Export Development Canada**

Alex Beliaev from Export Development Canada (EDC) started his talk by pointing to the small rate of utilization of real-estate properties, vehicles, and other types of assets. This has led to a new business model adopted by some companies such as UBER or Airbnb that aims at increasing asset utilization rather than merely focusing on improving their efficiency.

According to him, labor and capital efficiency were the major focus of the first three industrial revolutions, while resource efficiency is the key driver of the fourth industrial revolution. Substitution of non-renewable materials with recyclable ones, product design with the goal of waste elimination, increased circularity of used material, efficiency optimization, and asset virtualization were named as the five foundations of Industry 4.0. He also summarized the 5 pillars of Industry 4.0 as automation, digital factories, Internet of Things (IoT), the digital engineer and Artificial Intelligence (AI).

#### Siemens Canada

Michael Gardiner from Siemens Canada highlighted the following characteristics of Industry 4.0: connected humans, devices, and systems along the entire value chain; real-time access to information by all value chain stakeholders; and real-time optimization of the value chain. He also pointed to the application of Cyber Physical systems in production systems as information carriers that enable rapid adaption in such systems. Digitalization, and, digital twin and digital thread are key factors to building Industry 4.0 capabilities. The idea is to simulate products, people, processes, and resources, as well as to combine data and models to run what-if scenarios that address future challenges.

#### **CRIQ Innovation Partner**

**Francois Gingras** from CRIQ described projects related to Industry 4.0 technology that

were developed in CRIQ in collaboration with different sectors, most notably the lumber industry. Technology catch-up, integrated system optimization, analysis of digital capacity, identification of processes for automation were among some aspects he suggested manufacturers need to address for a successful shift to the Industry 4.0 paradigm. His talk was concluded by announcing that the first cyber-physical factory in Canada, manufactured by Festo Didactic, will be installed in Montréal and provides an industrial and academic experimentation lab for training and other value-added services.

#### **APN Perfection Multiplied**

Yves Proteau from APN Canada presented a brief history on the evolution of APN as a repair shop in 1950's into a modern Industry 4.0 organization in 2016. Most notably, he emphasized the role of ERP and data-driven decision-making as the key success factors in such a transformation. He pointed out the competencies APN expects from an Industry 4.0 workforce, namely, mechatronics, robotics, computer/data scientists, and mathematics. He concluded his talk by summarizing some future projects at APN such as accounting 4.0, dynamic planning, big data, AI, and energy management.

#### **ALIZENT Asset Interactive**

Yannick Larrivée from Alizent discussed the concepts of smart factories and proposed different guidelines and concepts for large and small manufacturers to embark on the journey to become a smart plant in an era where open software and hardware, cloud computing, artificial intelligence, augmented reality and other technologies are become more and more accessible. His talk was concluded by pointing out the importance of cybersecurity as smart plants will be intensively connected. He discussed some possible threats and tools used by hackers to create awareness and insight in possible solutions against such attacks.

#### Centre for Advanced Manufacturing, Concordia

Dr. Rolf Wüthrich, co-director of the Centre for Advanced Manufacturing at Concordia, emphasized the importance of developing flexible manufacturing technologies to meet the demands of Industry 4.0. He started by presenting the background of Industry 4.0 aiming to address the challenge of producing mass-personalized parts in economical ways. This asks for new processes. As example, he explained how electrochemical processes can potentially meet these demands. He showed different examples spawned off his research group, such as the development (together with Posalux SA) of a novel glass micromachining technology allowing for the production of ultra-customized glass parts and the development of electrochemical post-processing methods to handle complex shapes, including narrow inner surfaces, produced by metal Additive Manufacturing (AM).

### Advanced Control and Intelligent Systems (ACIS) Laboratory, UBC

Dr. Homayoun Najjaran, professor at the School of Engineering, University of British Columbia and leading the ACIS laboratory, pointed out that the provision of individualized mass customization in Industry 4.0, on the one hand, satisfies personalized needs, quality and cost constraints and, on the other hand, enables the businesses to respond to the environmental, energy and other global challenges. He detailed the key components of smart factories (smart machines and product components, communication networks, cloud services, and control terminals) and outlined that AI is the brain of the smart factory as the autonomy of production still requires the ability to analyze a great volume of data and determine the best possible actions in real time. AI provides reasoning and autonomous decision-making tools that can analyze and adapt to new situations. This is not a trivial task since decisions must be made based on uncertain information and imperfect data.

### Department of Mechanical, Industrial and Aerospace Engineering, Concordia

Dr. **Tsz Ho Kwok**, professor at Concordia University, focused on design and AM from 3D to 4D printing in the context of Industry 4.0. At first, he presented the attractive capabilities of AM as a manufacturing technology which pro-

vides designers "complexity for free" together with its current limitations as its low fabrication speed and the fact that built parts have anisotropic stiffness. Second, he introduced the core of 4D printing technology which are three key capabilities: the machine, the material, and the geometric program. This new manufacturing method fabricates a 2D self-folding structure, which can be automatically folded into a desired 3D shape by actuation mechanisms such as heating. Models fabricated by this method are smart, they can be self-sensing, self-assembling or self-shifting, and the procedure of fabrication is fast since only a few layers need to be made by AM.

#### Festo Didactic Canada

Michel Lessard from FESTO Didactic Canada discussed Industry 4.0 concepts in general for manufacturing plants. He presented the homemade MRP called Synchro which is implemented at the Festo Didactic Canada plant. This software is still running and will soon be connected with SAP as the main manufacturing module for this business unit. The main focus of his talk was on training needs and development to prepare future engineers and workers for the Industry 4.0 work environment.

#### Workshop

The full day workshop was designed for the Summer School to introduce Industry 4.0 concepts on a working model smart factory environment known as the Cyber-Physical (CP lab) and developed by Festo Didactic. The CP lab consists of individual workstations that can be arranged to form a realistic, flexible, industrial pallet circulating system. The system can be used as a teaching and research platform for various Industry 4.0 concepts as it integrates a proper dose of software programming, immersing students in the necessary digital environment required by Industry 4.0.

During the workshop, participants had the opportunity to manipulate the system and its programming the same way they would in a classroom. Trainers were on site to assist and answer questions and discuss topics of interest. Exercises were offered to push participants to rethink their understanding of traditional industrial engineering.

#### Future events on Industry 4.0

As a result of the great success of the school held at Concordia, Montréal, the UBC Industry 4.0 School & Industry Night was organized at the School of Engineering, Okanagan Campus, Kelowna, past February as follow up event bringing together professionals from academia, industry and government.

This summer – May  $27^{\rm th}$  2018 – a full day hands-on workshop on Industry 4.0 will be held during the CSME conference 2018.

LUCAS HOF, MSc is PhD candidate in the Department of Department of Mechanical, Industrial & Aerospace Engineering. He obtained both his Master's and Bachelor's degrees in Mechanical Engineering and Advanced Mechatronics from Delft University of Technology in The Netherlands. Together with Dr. Rolf Wüthrich and Posalux SA, he has co-developed a novel glass micromachining technology allowing the lean production of ultra-customized glass parts. To this day, Hof has cumulated over 10 years of teaching, entrepreneurial and industrial experience and produced over 30 journal and conference papers and one patent. Developing advanced manufacturing processes meeting the demand of Industry 4.0 and exploring new applications using glass for micro-electromechanical systems (MEMS) are among his research interests.

Dr. NADIA BHUIYAN obtained her bachelor's degree in Industrial Engineering from Concordia University and her MSc and PhD in Mechanical Engineering from McGill University. She taught at McGill and Queen's University. Her research focuses on product development processes. dealing with the design, development, production, and distribution of goods and services. After joining Concordia in 2002 as Assistant Professor in the Department of Mechanical, Industrial and Aerospace Engineering, Dr. Bhuiyan became Associate Director of the Concordia Institute of Aerospace Design and Innovation in 2003, and then Director of Education in 2015. She was promoted to Associate Professor in 2008, Professor in 2014, and served as Director of the Master of Aerospace Engineering program from 2008-2010. She is currently serving as the Vice-Provost of Partnerships and Experiential Learning.

Dr. MASOUMEH KAZEMI ZANJANI is an Associate Professor in the Department of Mechanical, Industrial & Aerospace Engineering at Concordia University. She received her PhD degree in Industrial Engineering from Université Laval. She is a member of OlQ and Informs and is also affiliated with CIRRELT research center in Montreal. Dr. Kazemi is the co-director of Center for Advanced Manufacturing at Concordia University and conducts several research projects on the application of stochastic and robust optimization in decision-making under uncertainty with a particular focus on manufacturing and healthcare sectors. Data analytics in healthcare and supply chain transformation for Industry 4.0 are among her other research interests.

Dr. ROLF WUTHRICH is an Associate Professor, in the Department of Department of Mechanical, Industrial & Aerospace Engineering as well as in the Department of Chemical and Material Engineering, at Concordia University. He received his PhD from the Swiss Federal Institute of Technology, Lausanne in 2003. He is co-director of the Center for Advanced Manufacturing at Concordia and is holding a NSERC discovery accelerator award in Industry 4.0. His current research is developing new manufacturing processes meeting the demand of Industry 4.0.



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