# 2B – Progress Report

## Problem Statement

Designing and modelling soft robots is a difficult endeavour, as their geometries are complex and imprecise, and standard design methods and approaches are often insufficient.

This project aims to virtually evolve soft robots in a novel, efficient and accurate manner that allows for easy replicability and adaptability.

## Research Work Plan

Weekly meetings are held with Dr. Venter to monitor and discuss progress.

The project started with extensive research, consisting of multiple academic papers and a few textbooks, in order to build up the necessary background knowledge required to complete the project, as well as properly defining the scope of the project.

A basic element is defined from which several behaviours may be expressed. These elements will be used as building blocks for the soft bodies. These basic elements are only represented in 2D. Allowing for time and access to computational power, these elements may later be upgraded to 3D.

A recursive grammatic encoding will be used to define whole bodies composed of these basic elements, and large populations of multiple unique encodings will be evolved with genetic algorithms in order to obtain near-optimal designs.

## Results

The main work done on the project thus far has consisted of thorough background research and defining the scope of the project comprehensively, and preliminary definition of

An extensive literature review has been done on the fields of soft robotics [1], their applications [2]–[4], the types of soft robotic actuators and their respective methods of actuation [5]–[11], the materials used in their construction [12], and design methods and processes usually applied to them [13]–[16].

The literature review also covered genetic algorithms [17], their first uses in evolving virtual bodies [18], [19], and various attempts at using them to evolve soft robotic bodies [15]. These attempts included modelling bodies with voxels [20], [21], tetrahedrons [22], and Gaussian distributions [23].

A more efficient and accurate modelling approach to soft bodies was desired, and thus potential methods of achieving this were investigated. The phenomenon of complex emergent properties from simple systems of rules was thus explored [24]–[26]. Following on this, an in-depth study of Lindenmayer systems (L-systems) was conducted [27]–[32], as well as Compositional Pattern Producing Networks (CPPN) [33], in order to determine the best novel modelling approach.

Extensive research has also been done on the finite element method (FEM), with special focus given to non-linear FEM with hyper-elastic materials [34]. Different models such as the Mooney-Rivlin and Ogden models were investigated, as well as the applicability of implicit and explicit solvers.

Following on the research done on FEM, different FEM software packages were considered. Following along with [34], non-linear FEM software was written. The advantages of using software written specifically for the project include exact knowledge and control of the operation of the software, but disadvantages include a lack of support if problems arise.

Following this, proprietary software including Siemens NX 12 and LSDyna were investigated, to determine their merits over that of custom software. It was determined that LSDyna would be suitable for the purposes of this project. It is versatile, robust, and allows for a great amount of user control. Additionally, support is available if needed.

Work has commenced on succinctly defining a basic element from which varying behaviours will be defined. This basic element is a simple square to which an internal pressure is applied and is composed of a material with a non-linear response.

## Work To Be Completed

As soon as the basic element has been completely defined and modelled non-linearly and sufficiently accurately, representing and defining this element using a recursive grammatic encoding will be done, followed by applying a genetic algorithm to evolve bodies comprised of these elements.

Further investigations may be done into 3D representation of these elements, as well as other shapes such as triangles or hexagons.

Additionally, a paper will be completed to be published by the end of January 2020 discussing these basic elements and their representation.

## Progress On Thesis

A rough draft of the project scope and literature review has been completed.

# References

[1] G. M. Whitesides, “Soft Robotics,” *Angew. Chemie - Int. Ed.*, vol. 57, no. 16, pp. 4258–4273, 2018.

[2] F. Ilievski, A. D. Mazzeo, R. F. Shepherd, X. Chen, and G. M. Whitesides, “Soft robotics for chemists,” *Angew. Chemie - Int. Ed.*, vol. 50, no. 8, pp. 1890–1895, 2011.

[3] C. D. Onal, X. Chen, G. M. Whitesides, and D. Rus, “Soft mobile robots with on-board chemical pressure generation,” *Springer Tracts Adv. Robot.*, vol. 100, pp. 525–540, 2017.

[4] R. F. Shepherd *et al.*, “Multigait soft robot,” *PNAS*, vol. 108, no. 51, pp. 20400–20403, 2011.

[5] P. Boyraz, G. Runge, and A. Raatz, “An Overview of Novel Actuators for Soft Robotics,” *Actuators*, vol. 7, no. 3, p. 48, 2018.

[6] C. J. Campagnuolo and H. C. Lee, “Review of some fluid oscillators,” *U.S. Army Mater. Command*, 1969.

[7] T. N. Do, H. Phan, T.-Q. Q. Nguyen, and Y. Visell, “Miniature Soft Electromagnetic Actuators for Robotic Applications,” *Adv. Funct. Mater.*, vol. 28, no. 18, p. 1870116, 2018.

[8] R. Mutlu, G. Alici, X. Xiang, and W. Li, “Electro-mechanical modelling and identification of electroactive polymer actuators as smart robotic manipulators,” *Mechatronics*, vol. 24, no. 3, pp. 241–251, 2014.

[9] J. N. Rodriguez, C. Zhu, E. B. Duoss, T. S. Wilson, C. M. Spadaccini, and J. P. Lewicki, “Shape-morphing composites with designed micro-architectures,” *Sci. Rep.*, vol. 6, no. June, pp. 1–10, 2016.

[10] P. K. Sekhar and V. Uwizeye, “Review of sensor and actuator mechanisms for bioMEMS,” *MEMS Biomed. Appl.*, pp. 46–77, Jan. 2012.

[11] A. Villoslada, A. Flores, D. Copaci, D. Blanco, and L. Moreno, “High-displacement flexible Shape Memory Alloy actuator for soft wearable robots,” *Rob. Auton. Syst.*, vol. 73, no. October 2017, pp. 91–101, 2015.

[12] J. P. Weyant, “Introduction and overview,” in *Mechanics of Solid Polymers*, 2015, pp. 1–16.

[13] D. R. Ellis, “Generative Design Procedure for Embedding Complex Behaviour in Pneumatic Soft Robots by,” Stellenbosch University, 2020.

[14] H. Gao, Y. Xu, Y. Han, S. Zhu, and Y. Zhou, “The convenient assembly method for the virtual robot kit,” *2016 IEEE Int. Conf. Mechatronics Autom. IEEE ICMA 2016*, pp. 2547–2551, 2016.

[15] J. Hiller and H. Lipson, “Automatic design and manufacture of soft robots,” *IEEE Trans. Robot.*, vol. 28, no. 2, pp. 457–466, 2012.

[16] D. Rus and M. T. Tolley, “Design, fabrication and control of soft robots,” *Nature*, vol. 468, pp. 467–475, 2015.

[17] A. A. Groenwold, N. Stander, and J. A. Snyman, “A regional genetic algorithm for the discrete optimal design of truss structures,” *Int. J. Numer. Methods Eng.*, vol. 44, no. 6, pp. 749–766, 1999.

[18] K. Sims, “Evolving virtual creatures,” *ACM*, pp. 15–22, 1994.

[19] K. Sims, “Evolving 3D morphology and behavior by competition,” *Artif. Life*, vol. 1, no. 4, pp. 353–372, 1994.

[20] N. Cheney, J. Bongard, and H. Lipson, “Evolving Soft Robots in Tight Spaces,” pp. 935–942, 2015.

[21] N. Cheney, R. MacCurdy, J. Clune, and H. Lipson, “Unshackling evolution: evolving soft robots with multiple materials and a powerful generative encoding,” *Heal. Psychol.*, vol. 24, no. 4, Suppl, pp. 167–174, 2013.

[22] J. Rieffel, D. Knox, S. Smith, and B. Trimmer, “Growing and Evolving Soft Robots,” *Artif. Life*, vol. 20, no. 1, pp. 143–162, 2013.

[23] J. D. Hiller and H. Lipson, “Evolving amorphous robots,” *Artif. Life XII Proc. 12th Int. Conf. Synth. Simul. Living Syst. ALIFE 2010*, pp. 717–724, 2010.

[24] R. I. Damper, “Editorial for the specialissue on ‘emergent properties of complex systems’: Emergence and levels of abstraction,” *Int. J. Syst. Sci.*, vol. 31, no. 7, pp. 811–818, 2000.

[25] R. Southwell, J. Huang, and C. Cannings, “Complex Networks from Simple Rewrite Systems,” *arXiv Prepr. arXiv1205.0596*, 2013.

[26] A. Zakinthinos and E. S. Lee, “Composing secure systems that have emergent properties,” *Proc. Comput. Secur. Found. Work.*, pp. 117–122, 1998.

[27] G. S. Hornby and J. B. Pollack, “The advantages of generative grammatical encodings for physical design,” *Proc. IEEE Conf. Evol. Comput. ICEC*, vol. 1, no. December, pp. 600–607, 2001.

[28] G. S. Hornby and J. B. Pollack, “Body-brain co-evolution using L-systems as a generative encoding,” *Proc. Genet. Evol. Comput. Conf.*, 2001.

[29] G. S. Hornby and J. B. Pollack, “Evolving L-systems to generate virtual creatures,” *Comput. Graph.*, vol. 25, no. 6, pp. 1041–1048, 2001.

[30] L. C. Kim and A. Z. Talib, “A visual language framework for music rendering using L-System,” *Int. Conf. Vis. Imaging Simul. - Proc.*, pp. 47–52, 2010.

[31] J. Kolodziej, “Modeling hierarchical genetic strategy as a Lindenmayer system,” *Proceedings. Int. Conf. Parallel Comput. Electr. Eng.*, pp. 409–414, 2002.

[32] P. Prusinkiewicz *et al.*, *The algorithmic beauty of plants*, no. 1. 2004.

[33] C. Wolfe, “Understanding Compositional Pattern Producing Networks (Part One),” *Medium*, 2018. [Online]. Available: https://towardsdatascience.com/understanding-compositional-pattern-producing-networks-810f6bef1b88. [Accessed: 20-Oct-2019].

[34] N. H. Kim, *Introduction to nonlinear finite element analysis*. 2015.