

Ruhr-Universität Bochum
Fakultät für Geowissenschaften

Technomass: Linking Urbanisation to the
Metabolism of the Urban Ecosystem
Conceptualisation and Empirical Evidence

Habilitation Thesis
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November 2020

List of Articles

1. Wentz, E.A., York, A.M., Alberti, M., Conrow, L., Fischer, H., **Inostroza**, L., Jantz, C., Pickett, S.T., Seto, K.C. and Taubenböck, H., 2018. Six fundamental aspects for conceptualizing multidimensional urban form: A spatial mapping perspective. *Landscape and Urban Planning*, 179, pp.55-62.
2. **Inostroza** L., Baur R., Csaplovics E., 2013. Urban sprawl and fragmentation in Latin America : a dynamic quantification and characterization of spatial patterns. *Journal of Environmental Management*, 115, 87–97.
3. **Inostroza**, L. 2017. Informal urban development in Latin American urban peripheries. Spatial assessment in Bogotá, Lima and Santiago de Chile. *Landscape and Urban Planning*, 165. <https://doi.org/10.1016/j.landurbplan.2016.03.021>.
4. Zepp, H., Groß, L. and **Inostroza**, L., 2020. And the winner is? Comparing urban green space provision and accessibility in eight European metropolitan areas using a spatially explicit approach. *Urban Forestry & Urban Greening*, p.126603.
5. **Inostroza**, Luis, Zoé Hamstead, Marcin Spyra, and Salman Qureshi. 2019. “Beyond Urban-Rural Dichotomies : Measuring Urbanisation Degrees in Central European Landscapes Using the Technomass as an Explicit Indicator.” *Ecological Indicators* 96 (February 2018). Elsevier:466–76. <https://doi.org/10.1016/j.ecolind.2018.09.028>.
6. **Inostroza** L, Zepp H, Pickett STA, de Groot R (2020) Ecosystem Function. In: Filho WL, Azul AM, Brandli L, et al. (eds) Life on Land, Encyclopedia of the UN Sustainable Development Goals. Springer Nature Switzerland AG, pp 1–8
7. **Inostroza** L., 2014. Measuring urban ecosystem functions through ‘Technomass’ - a novel indicator to assess urban metabolism. *Ecological Indicators*, Volume 42, 10–19.
8. **Inostroza** L., 2018. The circularity of the urban ecosystem material productivity: the transformation of biomass into technomass in Southern Patagonia. *Sustainable Cities and Society*, 39(May), pp. 335–343. doi: 10.1016/j.scs.2018.03.001.
9. Spyra, M., **Inostroza**, L., Hamerla, A., Bondaruk, J., 2019 Ecosystem services deficits in cross-boundary landscapes: spatial mismatches between green and grey systems. *Urban Ecosystems*, 22(1), pp. 37–47. doi: 10.1007/s11252-018-0740-3.
10. Palme, M., L. **Inostroza**, and A. Salvati. 2018. Technomass and cooling demand in South America: a superlinear relationship? *Building Research & Information* 46: 864–880. doi:10.1080/09613218.2018.1483868.
11. **Inostroza** L., Palme M., de la Barrera F., 2016. A heat vulnerability index: spatial indexes for exposure, sensitivity and adaptive capacity for Santiago de Chile. PLOS one. DOI 10.1371/journal.pone.0162464.
12. **Inostroza**, L., Zasada, I. and König, H.J., 2016. Last of the wild revisited: assessing spatial patterns of human impact on landscapes in Southern Patagonia, Chile. *Regional Environmental Change*, pp.1-15.
13. **Inostroza**, L., Zepp, H., 2020. The metabolic urban network: Urbanisation as hierarchically ordered space of flows, *Cities* (*in press*)

To Leon, mentor and friend

To my son Damian

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Acknowledgements

I would like to express my sincere gratitude to Prof. Dr. Harald Zepp for his invaluable support, trust, thoughtful criticism and kindness, without which this habilitation would not have been possible. I moved to Bochum without high expectations, but I found joy, challenges and academic comfort in working with such a tremendous scientist and the kind person. I have fully enjoyed the time I have spent working with Harald at the Ruhr University Bochum. I am eager to further develop all the ideas we are still discussing and developing.

Additionally, I would like to express my sincere gratitude to Jose Fariña for believing in me in a moment of my life when I thought that becoming a doctor was out of my league; to Christine Fürst, for her support at the beginning of my scientific career; to Leon Braat, who led me to the major leagues in the scientific editorial environment while shaping my editorial style with a constant flow of knowledge, critical approach, positive attitude and fascinating anecdotes; to Steward Pickett for his incredible kindness and scientific inspiration; and to Erik Gomez-Baggethun, a beautiful person and a permanent source of intellectual admiration. To the last two mentioned, I have learned so much from you both! I will never forget our scientific elucubrations under Patagonian skies.

I am also grateful to the myriad of co-authors (who are also good friends) listed in the papers cited in this habilitation: Marina Alberti, Francisco de la Barrera, Rolf Baur, Jan Bondaruk, Elmar Csaplovics, Dolf De Groot, Zoé Hamstead, Claire Jantz, Hannes König, Massimo Palme, Salman Qureshi, Agnese Salvati, Marcin Spyra, Karen C. Seto, Hannes Taubenböck, Libby Wentz, Abigail York and Ingo Zasada. It has been a tremendous pleasure and an honour for me to have the chance to collaborate with all of you.

I met so many people during the long journey of developing these ideas: tremendous scientists and some good friends who were always willing to provide thoughtful advice or to take the time to discuss a controversial idea, just for the pleasure of having an intellectual challenge. To Martina Artmann, Jan Bogaert, Jürgen Breuste, Peilei Fan, Anna Hersperger, Alina Hossu, Qingxu Huang, Cristian Ioja, Nadja Kabisch, Daniele La Rosa, Stephanie Pincetl, Jochen Schanze, and Weiqi Zhou: thank you very much! It has been a privilege for me to have had the chance to meet all of you along the way during my academic career.

I would like to dedicate this thesis to my forthcoming (hopefully!) grandchildren, even if it will be a long time before I meet them. I deeply hope that by the time they read these pages, most of these ideas will be reflected by a strong, substantial, and meaningful brand new urban science. I deeply hope that future generations will master their urban metabolism at all the scales at which it occurs, rather than letting urban metabolism master their lives.