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Research proposal [Part B1]
(Part B1 is evaluated both in Step 1 and Step 2,
Part B2 is evaluated in Step 2 only)

Urban Economic SEGregation: integrating explanatory mechanisms across geographical scales to compare remediatory policies in silico

SEGUE

Principal Investigator:
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Project hosted by:
Delft University of Technology (TU-Delft), The Netherlands

Duration of the project proposed:
60 months (5 years).

Panel: SH7. Human Mobility, Environment, and Space.

Proposal Summary (2000 characters)

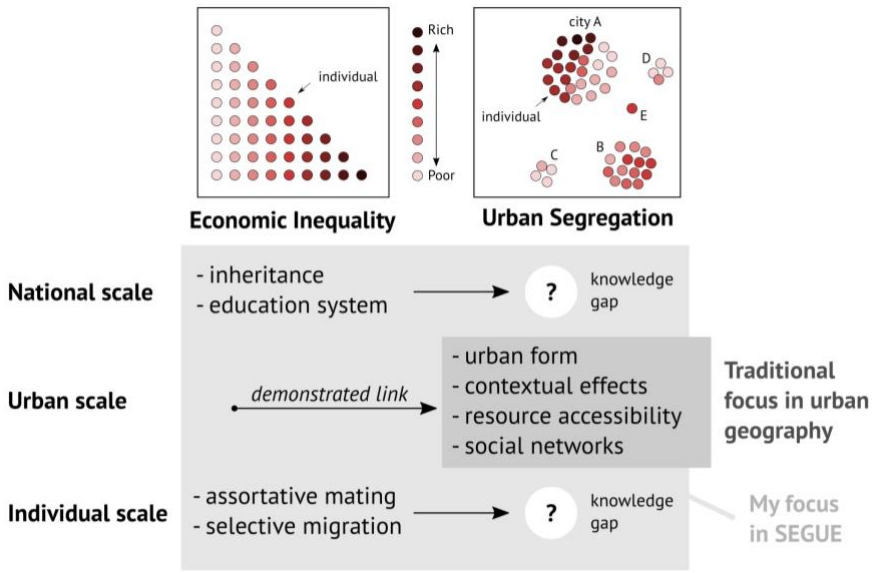
The uneven concentration of people and economic resources in cities hampers the well-being and opportunities of poorer citizens and represents a threat to social cohesion. It is considered a major policy challenge by researchers and international institutions alike. My aim with the SEGUE project is to identify and model the combination of economic, geographical and demographical drivers of urban economic segregation in order to better understand its dynamics and to better assess possible remediatory policies. The existing literature on urban segregation mainly explains urban economic segregation with sociological and intra-city factors (resource accessibility, social networks, contextual effects and the urban form) but also acknowledges a link with the evolution of economic inequality. The existing literature on economic inequality, by contrast, mainly focuses on factors operating at the national and individual levels (selective migration, assortative mating, family inheritance, education). My project addresses this gap by spatialising the national and individual explanations of economic inequality relating to residential mobility or the tax and education system, and by integrating these into a simulation model of urban segregation. This model will be calibrated with a uniquely rich source of exhaustive and longitudinal individual data from the Netherlands. Its analysis will produce new insights about the interaction between drivers of economic inequality and segregation in cities and will provide a cost-effective tool to compare policies to reduce urban economic segregation at different scales of action (local, urban, national), *ex ante* (i.e. within the virtual laboratory of a simulation) instead of *in situ* with costly and risky experiments. The results obtained from the research should also open new perspectives to study various forms of inequality and facilitate the study of economic segregation in other national contexts.

Section a: Extended Synopsis of the scientific proposal (5 pages)

AIM: With SEGUE, I aspire to integrate multidisciplinary knowledge about economic inequality and urban segregation to better understand and counter the dynamics of economic segregation in cities. I aim to **identify and model** the main drivers of **urban economic segregation** to **test and compare remediatory policies at three geographical scales**: national, urban and individual.

The uneven concentration of people and economic resources (typically: income and wealth) in cities dates back from the origins of urban polities and the diversification of social statuses (Nightingale, 2012). It renders the unequal organisation of society visible in space. Nowadays, changes in economic inequality translate into urban economic segregation with a couple of decades delay within cities (Tammaru et al., 2020). Economic inequalities and segregation in cities are considered top priority challenges by the United Nations (Sustainable Development Goal #10 and #11). Tackling them is urgent because 1) economic inequality and urban segregation restrict the ability to get by in life, life expectancy, social justice and cohesion, 2) inequalities are on the rise, and 3) policies aimed at reducing them have proved relatively ineffective in the last few decades. Urban space is not only a **magnifier** of economic inequalities (rendering inequality visible), it has also been revealed to be an **amplifier** of disparity in life chances through contextual effects, especially for poorer urban dwellers interacting in poor environments (Wilson, 1987). Despite the acknowledged link between economic inequality at the national scale and economic segregation at the city scale (Reardon and Bischoff, 2011; Tammaru et al., 2020), **urban geography has fallen short of explaining how the drivers of economic segregation work together through scale levels to produce and maintain segregation in a given urban system, locally and in relation to other cities, and how it can be reduced effectively.**
My hypothesis is that explaining the causes of urban economic segregation and countering its effects cannot be done within city limits, but has to include dynamical processes which extend beyond the city (figure 1). I argue that the knowledge gaps relating to the evolution of urban economic segregation in multiple cities can be reduced first, by accounting for the economic composition and inequality dynamics of the entire system (nationally), and second, by accounting for individual and family trajectories of economic mobility, through a focus on demographic factors and wealth transmission. Although these national and individual processes are well documented empirically and theoretically, there is a real knowledge gap in understanding where they materialise (between and within cities) and how they interact with other spatial processes. **The innovation of my project is to consider, for the first time, the analysis of processes of (re-)production of inequality which affect the spatial distribution of economic groups in cities through the construction of a modular agent-based model, calibrated on exhaustive longitudinal and geolocated empirical microdata from the Netherlands.** My ultimate objective is to use this model to assess and compare different policy strategies (typical, past and current) to reduce urban inequality and economic segregation in a cost-effective and time-saving way: within the virtual laboratory of a simulation (*in silico*). This objective can only be fulfilled if the relevant drivers of urban economic segregation are accounted for jointly. When fulfilled, it will contribute to reducing inequality and segregation in cities, thus addressing fundamental aspects of social justice and cohesion.

Figure 1. Theoretical drivers of economic inequality and urban segregation by geographical scale



Research objectives (ROs)

RO1: uncover the theoretical interactions between the processes generating urban economic segregation at various scales. Because I aim to integrate the analysis of national processes of economic inequality, geographical processes of urban evolution and sociodemographic processes of individual trajectories, I will consider theoretical explanations of urban economic segregation which differ in spatial and temporal scales. This analysis of the dynamics of urban segregation from the individual to the national system of cities is ground-breaking in that it provides a better insight into the drivers of observed trends and their interaction, and how they unfold simultaneously between various geographical scales. For instance, not only would the spatial distribution of unequal economic groups be explained, but also how the composition of these groups came about in a city, determining its future evolution through path-dependence (Arthur, 1994), and why this composition is different from other cities of the same system. My approach will produce an encompassing theory and reveal the dependency between economic inequality and urban segregation, so that remediatory policies can be targeted at the right combination of causal drivers and thus be more effective at reducing economic segregation than current approaches. This project therefore goes beyond the blind spots of urban segregation theory at the city level by including the processes of how economic inequality is produced and reproduced between individuals over time, and how this affects economic segregation in cities.

RO2: "animate" (Manzo, 2014) this combination of explanatory processes of urban economic segregation using the frontier techniques of agent-based simulation. Agent-based models (ABMs) are a type of generative models where heterogenous entities (agents) make autonomous decisions about their course of action, based on their evolution and that of their environment (including other agents). ABMs have developed rapidly in recent years and are valuable tools to represent individuals in interaction with one another and with their environment, as well as the structures these interactions generate or reinforce. The exploration of ABMs with innovative techniques exploiting the potential of high-performance computing opens new grounds for theory building and the explanation of urban phenomena (Pumain and Reuillon, 2017; Lorscheid et al., 2019). The model I aim to develop represents individuals within households, involved in processes of urban segregation at three geographical scales (individuals, cities and towns, country). It will simulate the observed evolution of urban economic segregation in the Netherlands and provide a virtual laboratory of how people and cities respond to public policies *ex ante*. Its challenging multiscale structure and evaluation will push agent-based research forward, but will also produce a model of urban economic segregation which can be replicated to analyse other national case studies in the future, thanks to its modular structure: since some processes might be less relevant to other contexts, they can be deactivated without disrupting the simulation.

RO3: use this integrated model of urban economic segregation to develop, compare and assess policy scenarios of segregation reduction *ex ante*. The advantage of developing an integrated model of urban economic segregation is that it allows to test and compare remediatory policies at additional scales to curb economic inequality in cities, for instance policies targeting inequality nationally or groups of individuals at certain points in their life. This policy assessment *in silico* can be done at low cost compared to "real-life" experiments. Altogether, these objectives will enable me and my team to reach the overarching aim of the project: to integrate multidisciplinary knowledge to better understand and counter the dynamics of urban segregation and inequality, both theoretically and through the simulation model, resulting in 1) a new theory of urban segregation (made of a combination of partial theories), 2) a new tool to simulate its evolution over time and in various contexts, and 3) new insights on key elements and mechanisms for effective public policies to address the challenge of segregation in cities and reduce its adverse effects.

State of the art

Urban segregation is defined as the separation of social groups in urban space. It refers to the process of separation (intended or not) as well as its static result. In urban segregation studies, individuals are traditionally grouped by class, race and migration status (Massey and Denton, 1988; Musterd, 2020), sometimes by gender, age and position in the life cycle (Cowgill, 1978; Blackburn et al. 2002), but also by economic means (Jargowsky, 1996; Tammaru et al. 2020). Historical explanations of economic segregation, such as Burgess' (1925) or Alonso's (1964) models, link the distribution of economic groups in urban space to competition and the trading between living space in the suburbs and commuting costs to central jobs in a schematic monocentric North American city. "Despite the importance of understanding the connection between income inequality and income segregation, few studies have addressed [this] question (for exceptions, see Mayer [2000] and Watson [2009]). Moreover, while these studies find that increasing income inequality leads to (or is at least correlated with) increasing income segregation, they do not investigate the ways in which income inequality is linked to income segregation in depth." (Reardon and Bischoff, 2011, p.1092). **My first research goal thus stems from a gap in the literature regarding the dynamic and causal link between economic inequality and urban segregation.** It builds on the few studies which have documented the link between economic inequality and economic segregation within the boundary of individual cities, highlighting the role of education (because

students from richer backgrounds and with richer peers achieve better academic results, which in turn increase their prospect of earning higher wages, Mayer, 2000), of the housing market (through its segmentation, Watson, 2009), of the racial composition and discrimination (which perpetuates the relation between housing values and racial composition, especially in the United States: Reardon and Bischoff, 2011; Gibbons, 2018). It also builds on the larger literature on the dimensions of urban segregation (Massey & Denton, 1988) and the processes through which it is reproduced, such as: **1) the unequal access to urban resources in the city**, whereby the uneven distribution of resource such as fresh food stores, cultural or medical amenities affect the prosperity and well-being of populations (Vallée et al., 2010; Auchincloss et al., 2011), as well as the residential strategies of the richest groups (Cheshire et al., 2014; Boeing, 2018); **2) the influence of local social networks**, whereby local contacts determine the homogeneity of social groups and the economic opportunity they offer through strong and weak links (Granovetter, 1973; Sampson, 2012); **3) contextual effects**, whereby the local environment (the neighbourhood's built environment or educative landscape) produces a high correspondence between individual and economic characteristics of people who share it (Jargowsky, 2002; Andersson & Muster, 2010, Galster, 2012) ; **4) the constraints played by urban morphology**, whereby the density and connectivity of the city create more or less stratification on the housing market, i.e. more or less opportunity for economic groups to cluster spatially (Wheeler, 2006; Raimbault et al., 2019).

The SEGUE project goes beyond these city-based studies by accounting for processes which take place beyond the individual city (at the national scale) and within social groups (at the individual level). This question is urgent because we know that changes in economic inequality induce changes in urban segregation, but we do not know how and which configuration of drivers of economic inequality matters most in this relation: is it how wealth is transmitted across generations through inheritance, how the education system is organised nationally, how people choose their partner or their place of residence? Identifying these drivers will help increase the pool of policies options beyond city-level to target segregation reduction more effectively.

At the national scale, there is a very large literature documenting the evolution of economic inequality and its causes (Alacevich and Soci, 2017). This literature has been re-energised (e.g. Piketty, 2013; Atkinson, 2015) with the rise of national levels of income and wealth inequality globally since the 1980s, after decades of reduction of inequality levels. These studies have revealed the importance of individual characteristics (such as age, gender, education, ethno-racial features) as well as institutional structures (health and education systems, tax system, legal system, trade and globalisation) in determining the distribution of income and wealth and their evolution in society. However, **the underlying causes of the spatial distribution of national income and wealth remains a blind spot of the economics literature** (Piketty, 2015). The innovation of my project is to consider processes of (re-)production of inequality which affect the spatial distribution of economic groups in cities, i.e. to explicitly consider where the changes in economic inequality happen. In geography and urban studies, scaling studies and their ancestors have focused on the size effect in urban concentration of wealth and income, economic groups and inequality (Morgan, 1975). For instance, Sarkar et al. (2018) show that individuals from higher income deciles are disproportionately concentrated in larger Australian cities, whereas individuals with lower incomes are distributed in proportion to city population or concentrated in the smaller cities and towns. In my own work, I have identified a similar pattern for France, where the levels of wage inequality increase with city size regardless of the city definition chosen (Cottineau et al., 2019a). A recent study confirmed this trend for the United States (Mora et al., 2021). Regional economies also play a role here (Rodriguez-Pose, 2018)

At the individual level, I consider non-spatial processes of inequality (re)production, like intergenerational transmission of wealth via inheritance and the transmission of educational, cultural and social capital and by the action of cumulative advantages in finance, school and housing (Bourdieu & Passeron, 1970; Hertz et al., 2008), but also assortative mating (the tendency for persons of similar economic profiles to partner up, Schwartz, 2013). However, I will explicitly consider how these individual processes take place in particular locations and how the geography of cities interact with their unfolding. A crucial channel through which this happens is through residential mobility. For instance, residential migrants with different education levels have been found to restructure the distribution of income and wealth nationally, between cities and region, whereby the most talented individuals are more likely to leave small cities and regions not densely populated, and to join large cities and populous regions in Sweden (Keuschnigg et al. 2019). In the UK, a long tradition of climbing metaphors attributes the rise in income of migrants moving to London to an *escalator effect* (Fielding, 1992), whereby each year spent working in London confers an economic advantage to the worker compared to its counterpart outside London, and to an *elevator effect* (Gordon et al., 2015), whereby the move to the capital provides them a one-off increase in income. These processes affect both the income distribution at the national level, its spatial distribution between cities and regions, and economic composition within the places of departures and arrival of residential migrants. Further non-spatial processes such as assortative mating and inheritance will concur to modify individual economic trajectories which, in accumulation, can affect the

patterns of economic inequality and urban segregation. **Although these individual processes are getting better documented empirically and theoretically, there is a real knowledge gap in the understanding of their interaction, mostly because these processes are studied at different scales (RO1).** This might explain why empirical situations are not well understood, and why policies have failed to reduce segregation. For instance: how does assortative mating (usually studied at a national scale) interact with migration to escalator regions to increase urban inequality and segregation? Is there a scaling pattern in trajectories of economic inheritance?

My project addresses this gap by combining different sets of explanatory processes of urban segregation dynamically into a single model. I have chosen the agent-based simulation framework to do so, because it allows for better representations of individual lifecourse trajectories, within neighbourhoods, within cities, within a national system of cities. I will use a frontier method of model-building and model exploration which has proven successful for analysing urbanisation (Cottineau et al., 2015a) and social segregation (Cottineau et al., 2018). **The incremental technique of model-building and exploration I have developed** (Cottineau et al., 2015b; Cottineau et al. 2019b) **is innovative because it isolates better the effect of each mechanism and each interaction of mechanisms, but also because it facilitates the reuse and replication of the model to further case studies, by adapting its modular structure (RO2).** This technique will be applied in SEGUE to the completely new challenge of a multiscale model. The model and its structure *(i.e.* the mix of active mechanisms) will be calibrated on individual empirical data from exhaustive Dutch register data since 2011.

Finally, this project will rely on the literature on policy assessment to reduce urban segregation at the city and neighbourhood level (mixing policies through residential relocation [e.g. de Souza Briggs et al., 2010] or transport and accessibility policies [e.g. Yang et al. 2015]), income inequality at the individual level (income and wealth tax [e.g. Piketty, 2013] as well as education policies [Solga, 2014]), as well as combination of place-based and people-based policies (Manley et al. 2013). **The objective is to implement these policies in the simulation model and to compare their ability to reduce urban economic segregation in silico (RO3)**.

Workplan. My project will be organised in four methodological phases.

Phase 1: select the mechanisms driving urban economic segregation and analyse their theoretical interactions. My team and I will analyse the processes considered necessary to explain urban segregation at different scales. We plan to focus on at least eight main processes: four at the intra-city scale (resource accessibility, social networks, contextual effect and the urban form) and four at the national and individual levels (selective migration, assortative mating, family inheritance, education). Each of these processes (and therefore potential mechanisms of urban inequality) will have to be unfolded, i.e. characterised in terms of their spatial scale and temporality, level of agents involved, type of inequality generated. We will also pay particular attention to how these processes interact with each other (e.g. does assortative mating reinforce, or reduce selective mobility? How does urban form interact with contextual effects?, etc.)

Phase 2: test the relevance of mechanisms and interactions empirically. The second methodological phase of the project will be to evaluate to which extent and in which particular configurations the selected processes contribute to the evolution of inequality and urban segregation in the Netherlands over the past decade. A PhD student under my supervision (PhD1) will do so using the exceptional data available for this country. Register data on Dutch residents, their residential trajectories, education and family ties coupled with administrative datasets on their employment history, income and tax levels in a secure environment allow to study economic inequality and urban segregation exhaustively at the level of the individual. Indeed, all registered residents are recorded, over time (since 2011 for wealth variables, and since the 1990s for other individual characteristics) and located at the residential address level (or regular squares of 100m x 100m), multidimensionally because migration trajectories can be related to educational and family characteristics through individual identifiers. We will use statistical modelling (including multilevel and geographically weighted regressions) and spatial analysis to test statistical associations between the selected hypothetical drivers of inequality (such as education differences, assortative mating, migration, wealth transmission) and of urban segregation (resource distribution, social networks, contextual effects and urban form) with the evolution of urban economic segregation in cities and towns of the Netherlands.

These first two phases are designed to uncover and align the theoretical and empirical interactions between the processes of urban segregation at various scales, thus fulfilling the first research goal.

Phase 3: build a modular agent-based model of urban economic segregation. The task for a postdoctoral researcher (PDR) in computer science and a PhD student (PhD2) in computational social science will be to work together, under my supervision, on building a modular and incremental agent-based model of urban economic segregation, made of the most relevant (combinations of) mechanisms suggested by the first two phases of the project. Instead of assessing the co-occurrence of inequality, segregation and some factors assumed to cause them (as with statistics), the simulation approach consists in assuming that causal processes are at work: for instance, we implement a rule whereby graduates look for endogamous partners and cause an

increase in income inequality and an increase in the concentration of graduates in the part of the city they reside in, therefore generating more segregation. This is the principle of generative modelling (Epstein, 1999; Manzo, 2014). We initialise the model on the situation of the Netherlands at the beginning of the period (2011 for economic variables), and we validate the plausibility of this causal mechanisms by comparing the resulting simulated configuration with the empirical situation in the Netherlands in 2021. However, instead of testing eight mechanisms separately, we aim to include them and their interaction as modules into a single model, whose structure (i.e. the mix of active mechanisms) is calibrated alongside its parameters. **This operation has only been tried with simpler structures of models and at a single scale (Cottineau et al. 2015a). Its application to a more complex and multiscale model will yield ground-breaking results for urban studies as well as agent-based modelling, but is very challenging conceptually and technically.** While collaborating closely, the PDR – being a computer scientist – will be responsible for the fact that the code implemented does what we intend it to do (model verification) whereas the PhD2 – being a social scientist – will be responsible for the mechanisms implemented in the model to adequately represent the social processes observed empirically (model validation). We will also work with a scientific sub-contractor on model robustness and analysis to tackle the challenges of high-performance computing in generating and analysing results with high dimensionality. Indeed, the number of simulations needed to disentangle the contribution of each mechanism and interaction of mechanisms to the overall result will be counted in millions or billions, require the use of cutting-edge model evaluation techniques (robustness and sensitivity analysis in particular) and access to high-performance computing facilities (including the Delft High Performance Computing Centre and the new supercomputer purchased by TU-Delft for researchers). Altogether, this simulation model will "animate" this combination of explanatory processes of urban segregation, thus fulfilling the second research goal.

Phase 4: implement and compare policy scenarios. The last phase of the project will consist in implementing various policy as scenarios in the simulation to reduce urban economic segregation in the model. Such scenarios will correspond to typical policies experimented with in the Netherlands (social housing, renewal subsidies, mixing policies) and elsewhere (housing vouchers), as well as new ideas (universal income for instance). The PhD2 under my supervision will use the simulation model to compare their effects urban economic segregation reduction, thus providing a cost-effective tool for policy evaluation and fulfilling the third research goal.

High risk / high gain assessment

The main originality of this workplan is its theoretical and empirical integration of explanatory processes across scales and disciplines through individual-based simulation in a system of cities. This is rendered possible by the availability of microdata in the Netherlands (to which I already have access as a CBS accredited researcher) and of a new supercomputer at TU-Delft. **A significant novelty of my methodological plan lays in its reproducibility thanks to the modular structure of the model.** This way, the model is calibrated to represent the economic evolution of the Netherlands and its cities, but it can be adapted to further case studies by adding, deactivating or modifying blocks of mechanisms. Finally, the comparison of policies at different geographical scales is an innovative take on policy evaluation to reduce economic segregation in cities. **The project faces the challenge of creating alternative, competing and complementary explanations to the evolution of urban segregation which cannot be properly disentangled due to equifinality** (i.e. the principle that a system's end state can be reached by many potential routes, or by the action of different mechanisms in our case). Regarding model comparison and selection (phase 3), we will mitigate this challenge by exploring the model extensively with cutting-edge methods I have contributed to develop to analyse model sensitivity (Chérel et al., 2015; Cottineau et al., 2015, Raimbault et al., 2019) and by developing new ones: for instance, a calibration method which can handle model structures with different geographical scales involved.

The successful development of the SEGUE project will lead to a better understanding of urban economic segregation, not only at the scale of one city but as a systemic phenomenon affected by macro-trends of economic inequality as well as micro-dynamics of families and individuals. It should equip this understanding with a tool to animate the evolution of urban economic segregation in the Netherlands and compare remediatory policy scenarios. This tool (the simulation model) is designed to be reproducible, i.e. scientifically sound, in accordance with the European policy on reproducibility and open science, but also reusable in other national contexts and by other research teams. The project's results will bring the geographical, economics and sociological approaches of urban segregation closer together, by demonstrating the interdependency of scales and processes favoured by each of them. **The better understanding of urban economic segregation and the modelling tool developed will allow my team to advise policy makers on the comparative effectiveness and side-effects of alternative policies to reduce urban segregation *ex ante*. This means that, while taking inspiration from previous *in situ* experiments, it will not require actual policy implementations before evidence of their effectiveness if confirmed.** New questions should also arise, regarding the transferability of our results to other forms of inequality and segregation, as well as to other national contexts.

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Wilson, W. J. (1987). *The truly disadvantaged: The inner city, the underclass, and public policy*. University of Chicago Press.

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Section b: Curriculum vitae

PERSONAL INFORMATION

COTTINEAU, Clémentine

ORCID: 0000-0002-2452-3901, http://clementinecttn.github.io/

Date of birth: 24 October 1988, Nationality: French

EDUCATION

2014 PhD
Geography, Université Paris 1 Panthéon-Sorbonne, France
PhD Supervisor: Prof. Denise Pumain.

2011 Master
Geography, Université Paris 1 Panthéon-Sorbonne, France

2009 Bachelor (x2)
Economics and Geography, Université Paris 1 Panthéon-Sorbonne, France

- **CURRENT POSITIONS**

2020 – Assistant Professor in Urban Studies
Urbanism Department, Delft University of Technology (TU-Delft), NL.

2018 – Permanent Researcher
Centre National de la Recherche Scientifique (CNRS), France.

- **PREVIOUS POSITIONS**

2014 – 2017 Research Associate
Centre for Advanced Spatial Analysis, University College London, UK.

2012 – 2014 Teaching Assistant
Geography, Université Paris 1 Panthéon-Sorbonne, France.

2010 – 2011 Research Assistant
Geography, Laboratory Géographie-cités, France.
Geography, North Federal University, Russia.

- **FELLOWSHIPS AND AWARDS**

2020 – 2020 9-months Visiting Fellowship, funded by (CNRS), France

2015 PhD Award "Philippe Aydalot" in Regional Science, ASRDLF, France.

2011 – 2014 PhD Scholarship, funded by Université Paris 1 Panthéon-Sorbonne, France

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS**

2021 – 1 PhD Student
Faculty of Architecture, Urbanism Department, TU-Delft, NL.

2014 – 2017 2 PhD Students / 4 Master Students
Centre for Advanced Spatial Analysis, University College London, UK.

2012 – 2013 1 Master Student
Geography, Université Paris 1 Panthéon-Sorbonne, France.

- **TEACHING ACTIVITIES**

2020 – Assistant Professor – Urban Studies and quantitative research methods, TU-Delft, NL.

2019 Invited professor – Urban modelling, University of Shanghai, China. (2 weeks)

2018 Instructor – Segregation modelling, Massive Spatial Data summer school, Italy. (5 days)

2012 – 2014 Teaching Assistant – Urban Studies & Spatial Statistics, University Paris 1, France.

- **ORGANISATION OF SCIENTIFIC MEETINGS**

2020 Co-organisor of the workshop "Urban Clusters" at UCL, UK. 1 day, 10 participants.
2015 – 2018 Co-organisor of special sessions on "Geosimulation" at conferences:
ECTQG 2015: 10 presentations, Italy / CIST 2018: 6 presentations, France.
2013 Part of the local organisation team of the 19th European Colloquium of Theoretical and Quantitative Geography (ETCQG). 5 days, 300 participants, France.

- **INSTITUTIONAL RESPONSIBILITIES**

2021 – Member of the department's Daily Board for Research, TU-Delft, NL.
2019 – 2020 Elected representative at the laboratory board, Centre Maurice Halbwachs, CNRS, France.
2018 – 2020 Organizer of the Internal Seminar, Centre Maurice Halbwachs, CNRS, France.
2013 – 2015 Elected representative at the Doctoral School board, University Paris 1, France.

- **REVIEWING ACTIVITIES**

Editorial Board Member
2021 – Environment and Planning B - Urban analytics and city science, UK.
2017 – Cybergeo, European Journal of Geography, France + Deputy Director for Data Papers.

Head of the book series "Geography of inequalities"
2018 – Coordinator of three books, co-editor of two of them, ISTE Group, Sciences Eds, UK.

Review panel member: Complex Networks 2020, online & Complex Systems Society 2017, Mexico.

Scientific reviewer:
2014 – *for academic journals*: Cybergeo x16, Environment and Planning B x6, PLoS-ONE x5, Cities x2, Intl J. of Geographical Information Science x2, J. of Artificial Societies and Social Simulation x2, Geoinformatica x2, PNAS, Annals of the American Association of Geographers, Urban Studies, Geographical Analysis, Transaction of the Institute of British Geographers, Regional Studies, Computer Environment and Urban Systems, Royal Society Open Science, Papers in Regional Science, Big Data and Society, Applied Geography, J. of Archaeological Science, International Regional Science Review, Regions & Cohesion, Geosciences, Mathematics, Regional Statistics, Europa Regional, Miscellanea Geographica, Intl J. of Environmental Research and Public Health, Géographie Economie et Société, Findings, L'Espace Géographique, EchoGéo.
2017 *for academic publishers:* Routledge.

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2017 – 2019 Member, Regional Studies Association (RSA), UK.
2015 – 2019 Founding Member, Network of researchers on urban complex systems *EIGHTIES*, France.

Accredited researcher for secure microdata access:
2020 – Census Bureau of Statistics (CBS), NL.
2018 – Centre d'Accès aux Données Sécurisées (CASD), France.
2016 – Office for National Statistics (ONS), UK.

- **MAJOR COLLABORATIONS**

Prof. Maarten van Ham, *Urban inequality and segregation*, TU-Delft, NL.
Dr. Julie Vallée, *Geography of inequalities*, CNRS, France.
Dr. Romain Reuillon, Dr. Julien Perret, Dr. Sébastien Rey-Coyrehourcq, Dr. Juste Raimbault & Dr. Paul Chapron, *Agent Based Modelling*, Complex systems institute, France.
Dr. Elsa Arcaute & Prof. Michael Batty, *Urban scaling and complex systems*, UCL, UK.
Prof. Denise Pumain, *Systems of cities analysis*, University Paris 1, France.

Appendix: All current grants and on-going and submitted grant applications of the PI (Funding ID)

Mandatory information (does not count towards page limits)

Current grants (Please indicate "No funding" when applicable):

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
PhD funding "urban circulation and the reproduction of inequality"	TU-Delft	~200 000 (four year fully funded PhD contract)	2021-2025	PhD supervisor and co-promotor	The PhD Student will be associated with the theoretical reflection of the SEGUE project on inequality and residential migration. They will help and collaborate with the PhD1 on microdata analysis, and also participate in some of the project activities (the policy workshop for instance).

On-going and submitted grant applications (Please indicate "None" when applicable):

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[2]

Section c: Early achievements track-record (max. 2 pages)

I have selected five publications to represent the diversity of contributions I have made to urban studies, economic geography and agent-based modelling, which are all relevant to the SEGUE project.

Order of importance	Reference	Main author	Independent research	Year of publication	Number of citations
1	Cottineau et al., *CEUS*	x	x	2017	118
2	Cottineau et al., *EPB*	x	x	2019	43
3	Cottineau et al., *Systems*	x		2015	21
4	Raimbault et al., *JASSS*		x	2019	15
5	Cottineau, *PLOS-ONE*	x	x	2017	27

1. **Cottineau**, C., Hatna, E., Arcaute, E., & Batty, M. (2017). Diverse cities or the systematic paradox of urban scaling laws. *Computers, environment and urban systems*, 63, 80-94.

My most important published article to this day is one I conducted as a postdoctoral researcher at the Centre for Advanced Spatial Analysis in University College London. It analyses the impact of city delineation on the size effect of cities on their economic specialisation and distribution of resources. It uses the framework of scaling to interpret size effects and their variations. As such, it has become a reference paper for urban scaling studies worldwide. The study developed in this paper allowed me to investigate in detail the diversity of cities in terms of morphology, specialisation and size, as well as the relationship between this diversity and the distribution of people and resources. Its insight still plays a role in how I approach the description of cities: as a set of diverse geographical objects whose demographic and economic composition is independent neither from their internal organisation nor from their position in the larger system of cities.

2. **Cottineau**, C., Finance, O., Hatna, E., Arcaute, E., & Batty, M. (2019). Defining urban clusters to detect agglomeration economies. *Environment and Planning B: Urban Analytics and City Science*, *46*(9), 1611-1626.

This article is a follow-up of the first one. It was published two years later with an additional co-author in a leading journal of my scientific field. The article reuses the methodology of the previous paper but applies it to the study of agglomeration economy, and the relation between city size, income inequality and income segregation. It marks my growing interest in the systematic investigation of these topics, which culminates with my move to the Urban Studies group at TU-Delft and the development of this ERC project. The article shows that income inequality is on average higher in cities of larger population in France, but that the relation with income segregation is more complex. Indeed, the measurement of segregation depends on how cities are delineated, i.e. on their morphology. This result is a stepping stone to my ERC project, which seeks to unpack the production and reproduction of urban economic segregation beyond the correlation with city size.

3. **Cottineau**, C., Reuillon, R., Chapron, P., Rey-Coyrehourcq, S., & Pumain¨, D. (2015). A modular modelling framework for hypotheses testing in the simulation of urbanisation. *Systems*, *3*(4), 348-377.
¨ Prof. Denise Pumain supervised my PhD.

My most significant contribution to the interdisciplinary field of urban studies and agent-based modelling was published in a rather confidential journal (although indexed in Scopus), but as part of a very relevant special issue ("agent-based modelling of city systems") directed by Koen H. van Dam and Rémy Courdier, two experts of the field. It has still generated close to 3000 reads and 21 citations. The article describes the ground-breaking model-building method I have developed as part of my PhD research. It consists in assembling explanatory mechanisms of the evolution of a system of cities as building blocks in a modular agent-based model. The method includes a novel way of calibrating such multimodels using genetic algorithms (with high performance computing) to identify the mix of mechanisms most relevant to simulate a particular empirical trajectory. In the case of this research article, the empirical trajectory to simulate was the differential growth of cities in the Soviet and post-Soviet space, and the building block mechanisms referred to five theories of differentiatial urbanisation: spatial interactions, size effects, site effects, situation effects and territorial effects. I will make use of this unique and innovative framework to build and evaluate a model of urban segregation in my ERC project, on the very challenging new case of a multi-scale model.

4. Raimbault, J., **Cottineau**, C., Le Texier, M., Le Néchet, F., & Reuillon, R. (2019). Space Matters: Extending Sensitivity Analysis to Initial Spatial Conditions in Geosimulation Models. *Journal of Artificial Societies and Social Simulation*, *22*(4).

My participation to the development of ground-breaking methods to explore geosimulation models and to derive theoretical knowledge about cities from agent-based models is acknowledged in this more recent article lead by a junior colleague, while I was a tenured researcher in France. It describes an unprecedented way to assess the impact of initial spatial conditions on a geosimulation model's results, i.e. how the urban morphology chosen at the start of a simulation (a monocentric or polycentric city for instance) constrains the diversity of patterns the model can generate with a given set of explanatory mechanism. Despite a growing literature on agent-based models and their numerous applications to geographical problems, this issue has remained an absolute blind spot of research until our contribution in a leading journal for agent-based modellers from the social sciences. In the paper, we showed that polycentric cities produce systematically more segregation than monocentric cities at the end of a Schelling's model, for the same value of parameters. This project got me better acquainted with various existing models of segregation and their limits. Furthermore, the necessary attention to be given to initial spatial conditions in geographical agent-based models will be included in my assessment of this project's segregation model as well.

5. **Cottineau**, C. (2017). MetaZipf. A dynamic meta-analysis of city size distributions. *PloS one*, *12*(8).

Finally, this article is one of the five single-author peer-reviewed articles I have published since 2011, and the most cited one. It corresponds to a systematic meta-analysis review of empirical estimations of city size distributions. Its two most interesting features are the number of estimations gathered for the meta-analysis (1929, compared to 500 in a comparable meta-analysis published ten year before by V. Nitsch) and the linkage between this open-access article and a suite of open resources I developed: the entire database I have built, the source code to the analysis and an interactive online application where the reader can replicate the analysis and explore the data themselves by selecting relevant options and filters. I consider this work a proof of my research independence, since I conducted this project from start to finish on my own initiative. It also attests to my dedication to open science and scientific reproducibility.

Beyond these five publications, I can identify four areas of research achievement in my career, since the start of my PhD ten years ago:
- First of all, I have developed **a unique set of knowledge areas and skills in the fields of urban studies and quantitative methods**, which enable me to work on urban inequality from theory development to the constitution and analysis of large longitudinal databases, from the simulation of complex urban models to the engaging communication of results to different types of audience. I have been able to apply such varied skills to a broad range of urban subjects (metropolisation, urbanisation, scaling, mobility, economic clusters and segregation), at various scales and in various contexts (i.e. London, France, the Netherlands, the post-Soviet space). Yet my work is tied together by a strong focus on inequality, urban morphology, the nature and location of economic activities, the processes leading to the differentiation of cities' populations and a reflexive view on urban geography and the history of urban models.
- Second, I have contributed to urban studies and complex systems science by **collaborating with over 50 co-authors to publish 3 books, 18 peer-reviewed articles, 3 book chapters, 4 non-peer reviewed articles, 1 PhD monograph, 13 book reviews and 2 translations.** This expertise is recognized by the scientific community in geography, urban and regional studies as well as complex systems science, for example through the numerous requests I have received for scientific review (61 completed since 2014 for 33 different scientific journals), 6 invitations to speak at international conferences (including the European Forum Alpbach in 2015), 2 invitations to teach at international advanced schools (on spatial big data in Italy and on urban modelling in China) as well as numerous invitations to speak at local seminars around the world.
- Third, my contribution to urban studies and open science includes the provision of **2 datasets, 15 repositories of programming code and 4 websites under open-source license as well as 1 video tutorial and 2 sets of slides for teaching purposes on open access**. I also support open science and reproducibility by directing the publication of data papers for the scientific journal Cybergeo.
- Finally, my doctoral research has been distinguished by the 2015 **international prize "Philippe Aydalot" in regional science.** More generally, my early track record benefits from the opportunity to have conducted research under favourable conditions (including as a tenured full-time researcher since 2018) alongside promising and experienced colleagues at prestigious European institutions.

ERC Starting Grant 2021
Part B2
(not evaluated in Step 1)

Sections (a) and (b) of Part B2 should not exceed 14 pages. References do not count towards the page limits.

The spatial separation of urban dwellers based on their economic means has serious adverse consequences on the poorer individuals' well-being and on society as a whole, which remediatory policies have failed to counter effectively over the past decades. It therefore remains an academic challenge and sits at the top of the agenda of international institutions (e.g. United Nations' Sustainable Development Goals [SDG] #10 and #11). My aim with the SEGUE project is to identify and model the combination of economic, geographical and demographical drivers of urban economic segregation in order to better understand its dynamics and to better assess possible remediatory policies. It innovates on two levels: first, it bridges a gap in the literature by focusing on the spatialisation of national and individual explanations of economic inequality and their interaction with city-level processes of urban segregation; second, it does so through a sequence of theoretical integration, empirical validation and generative modelling. The multiscale agent-based model I plan to build will be calibrated with a uniquely rich source of longitudinal data about individual economic and geographical mobility in the Netherlands. It will be used to explain the observed evolution of segregation, but also a virtual laboratory in which to compare remediatory policies in terms of cost, side-effects and efficiency.

Section a. State-of-the-art and objectivese

Introduction.
Urban segregation is defined as the spatial separation of social groups in cities, both in terms of the process of separation (dynamic) and to its resulting geographical configurations (static), i.e. the uneven distribution of social groups in various blocs, neighbourhoods, districts and areas of cities. It can be approached through the multiple contexts within which urban dwellers experience segregation at different times of the day and while performing different activities (Kwan, 2013; van Ham and Tammaru, 2016; Vallée, 2017; Le Roux et al., 2017; Park and Kwan, 2018; Wang et al., 2018), but the dominant focus of urban segregation studies (this project included) is on where people reside, since it reflects to a large extent their access to other areas and activities. While most authors describing segregation in America (Wilson, 1987; Massey and Denton, 1993; Wacquant, 1997) reserve the term segregation for the cases of intentional, legal or institutional separation against a minority group (typically African Americans); the term segregation is also used for cases where the separation is unintended (Schelling, 1971; Phillips, 2007; Smets & Salman, 2008; Morales et al., 2019; Musterd, 2020). Finally, the notion of urban segregation is complex and multi-dimensional, mostly because the attributes according to which individuals can be grouped are endless. In traditional urban segregation studies, individuals are most often grouped by class, race, income, religion, occupation and migration status (Massey and Denton, 1988; Musterd, 2020), but urban segregation by gender, age or position in the life cycle is also studied (Cowgill, 1978; Blackburn et al. 2002). Segregation being a multi-dimensional and multi-disciplinary concept, it cannot be explained by one theory alone (van Kempen, 2002), therefore many "middle-range" (Merton, 1968) theories exist to explain the emergence and persistence of spatial segregation of social groups in cities. In this project, I consider urban segregation as the process through which different social groups end up residing in distinct cities as well as in distinct urban neighbourhoods, intentionally or not. More particularly, my focus is on urban economic segregation, i.e. the spatial differentiation of urban societies along economic lines (income and wealth levels). Indeed, income and wealth determine to a large extent the housing options available to individuals, and therefore where they can afford to reside.

Unlike other domains of urban segregation, there has been a significant asymmetry between the rich development of theoretical accounts of **urban economic segregation** and the paucity of its empirical analysis, limited mainly by the scarce availability of relevant data at local geographical levels. Historical explanations of economic segregation, such as Burgess and Park's (1925) model, link the distribution of economic groups in urban space to a competition for space and the sorting of households based on their financial ability to outbid their competitors (Reardon & Bischoff, 2011). Following Alonso's (1964) model, there is a second factor determining the geography of economic groups in cities, which is the arbitrage households make between spending their income on larger living spaces in the suburbs and commuting to jobs centrally located or spending it on more expensive inner-city housing. The combination of the two models is characteristic of urban

economic segregation in monocentric North American cities, where inner cities concentrate the poorer groups of population while affluent groups reside mainly in the suburbs (Jargowsky, 1996). Since Hoyt (1939), the organisation of rich and poor urban groups in different sectors of the city (West and East for instance), depending on the differential in accessibility, is usually considered as a third pattern of urban economic segregation, verified in various national contexts (Berry & Kasarda 1977; Schwabe, 2007). A fourth pattern of urban economic segregation is that affluent groups of residents are more segregated spatially (i.e. more concentrated and isolated in specific neighbourhoods) than poor and middle-income groups (Duncan & Duncan, 1955; Reardon & Bischoff, 2011; Préteceille & Cardoso, 2020). This pattern still holds true but is complicated by the advent of gentrification trends, whereby affluent individuals and their capital invest in deprived and depreciated areas of cities (Smith, 1979; Lees et al., 2013), thus creating a temporary state of socioeconomic mix locally. Musterd et al. (2017) find evidence of these regularities also in European cities, but recall that the most divided European cities by income are less segregated than the least divided American cities. Beyond these broad patterns of urban economic segregation, "*relatively little is known about the spatial dimensions of rising socioeconomic inequality*" (Musterd et al., 2017, p. 1062). In particular, it is not clear how the current rise in income and wealth inequality in most countries (Alvaredo et al., 2018) translates in terms of inequalities between cities and of residential segregation within them: does it affect only the extreme segments of large metropolises or does it have consequences for migrations patterns and cities of smaller size? Can economic segregation be reduced regardless of the evolution of economic inequality? Since the interaction between drivers of urban segregation and drivers economic inequality need more research, these questions do not have a definitive answer at present. My project will contribute to address them.

"*Despite the importance of understanding the connection between income inequality and income segregation, few studies have addressed these questions (for exceptions, see Mayer [2000] and Watson [2009]). Moreover, while these studies find that increasing income inequality leads to (or is at least correlated with) increasing income segregation, they do not investigate the ways in which income inequality is linked to income segregation in depth."* (Reardon and Bischoff, 2011, p.1092). With respect to the temporality of their effect, Tammaru et al (2020) found a delay of a decade or so between changes in inequality and the subsequent changes in socioeconomic segregation in large European cities. The few studies which have documented the **causal link between economic inequality and economic segregation** within the boundary of individual cities, highlight the role of education (Mayer, 2000), of the housing market (Watson, 2009) and of the composition and discrimination of racial groups (Reardon and Bischoff, 2011). Sassen's (1991) hypothesis of social polarisation in global cities suggested a parallel evolution of increased inequality (due to the growth of the richest and the poorest groups) and increased segregation. "*The relation between polarisation and segregation is in fact more complex. [...] The two may change in relatively independent ways since the growth of segregation is primarily dependent on the mechanisms that allocate residential space to different social groups rather than on the degree of social polarisation or even on the range of income inequality. This is especially true when the land and housing markets are regulated in a spirit of decommodification (Musterd and Ostendorf, 1998a) or when marketisation is not strong enough to overwrite the influence of other factors (such as traditional family structures) in the allocation of residential space"* (Maloutas, 2004, p. 5). The mechanisms through which unequal groups of population are spatially allocated, both between cities and within them, are of crucial importance to our understanding of urban segregation.

Investigating urban economic segregation and understanding its drivers is crucial for social sciences for three reasons: 1/ because urban economic segregation has serious consequences for poor segregated groups as well as for the urban and national societies as a whole; 2/ because inequality and segregation are on the rise again; and 3/ because actions aimed at reducing them have proved relatively inefficient in the last few decades.

1/ Since the Chicago School of Sociology, the main take on **urban segregation is that it represents a problem to be addressed by researchers and policy makers** (Maloutas, 2004; Vaughan & Arbaci, 2011). Although the concentration of some social groups in space can be considered beneficial for the preservation of ethnic minority culture (Peach, 1996), it is not usually the case for economic groups. Indeed, when rich and poor urban dwellers live in separate parts of the city, they tend to experience unequal access to consumption, power, status, financial security, education, health and amenities (Power, 2012; Marmot, 2015). Where resources are scarce, people live shorter and more constrained lives, with fewer prospects of good education, health and income for their children. "*It is no exaggeration to say that segregation continues to be a matter of life and death for both individuals and communities*" (Gibbons, 2018, p.1). On the contrary, where wealth is plentiful, residents tend to enjoy a better environment, better professional prospects, a more secure valuation of their properties, etc. Furthermore, the spatial segregation of people along economic lines affects the cohesion, well-

being and prosperity of society as a whole (Wilkinson & Picket, 2009; Alacevich and Soci, 2017). Urban segregation and economic inequalities in general are considered one of the top 10 priority challenges in the world by the United Nations, and tackling this challenge can also help addressing other pressing problems such as poverty (SDG #1) and hunger (SDG #2). To address them, policy makers in general and urban planners in particular therefore have to rely on a robust scientific understanding of how urban inequality comes about and is (re)produced, in order to design policies which can curb it effectively. My project will contribute to this challenge, both theoretically and with a simulation tool on which to assess and compare policies *ex ante*.

2/ The problem of urban economic segregation has become particularly acute since the 1980s because **economic inequality within countries is on the rise again**, after decades of reduction of inequalities following WWII (Alvaredo et al., 2018). In 2015, the richest 10% individuals owned 72% of the entire national wealth in the United States, 67% in China, around 50% in West European countries and up to 87% in South Africa. The increased unevenness in income and wealth distribution results from larger trends in finance, labour markets and globalisation, for instance the polarisation and professionalisation of occupations, as was demonstrated for 24 global and capital cities by van Ham et al. (2021). Individuals of increasingly unequal economic means then elect residence in specific parts of a country, in specific cities and, within them, in specific neighbourhoods, affecting the dynamics of urban inequality. "*Regarding the changing levels of socioeconomic segregation, it is clear that metropolitan Europe has become a more unequal place. Essentially, the increasing spatial divisions between the top and the bottom of the social hierarchy parallel growing income inequality and global connectedness, as well as the region-wide retrenchment of the welfare state and the liberalization of housing systems. [...] Our study supports the view that the more liberal societies become, the higher the levels of segregation will be (perhaps with a time lag).*" (Musterd et al. 2017, p. 1076-8). This project will contribute to the understanding and modelling of economic inequality and urban segregation, dynamically and beyond the case of global and capital cities.

3/ Despite international institutions flagging the problem, despite multiple observatories tracking it with a diversity of indicators, **local and national policies do not address economic inequality and segregation in a way that significantly improves the situation.** "*Urban segregation designed to enhance elite groups' power and wealth extends back to the most ancient civilizations*" (Nightingale, 2012, p. 2). Recently referred to as escapist strategies (Smets & Salman, 2008) pursued by elite residents separating themselves from the city's fiscal and social landscape, for instance in gated communities, these tendencies have however consistently been met with resistance, from local disadvantaged groups or collective institutions, through urban planning, support to local economics and national interventions. "*Policies that focus on countering urban segregation often primarily attempt 'to keep society together'*" (Smets & Salman, 2008, p. 1319). Actions on housing provision and social mixing, through social housing in particular, have been a favoured pathway to reducing urban segregation, massively in the 1970s. "*In principle, social housing could provide a strong offsetting mechanism. However, in practice it does not because social housing is itself divided into more and less privileged neighbourhoods and, whilst there are exceptions, social housing itself is concentrated in poorer areas*." (Cheshire et al., 2014, p.61). Moreover, housing policies have failed to counter urban segregation because the uneven spatial distribution of wealth also depends on educational, social and economic processes happing at higher scales (the metropolitan areas, the region, the nation) which "*cannot all be controlled by local urban politicians; consequently, other types of interventions may have more effect*" (Andersson & Musterd, 2010, p. 40). This project, by our understanding of those interaction between multiscale drivers of urban economic inequality and providing a ground-breaking simulation tool, will offer a new take on the problem of urban economic segregation and its potential policy remedies.

Research objectives

In this view, the overall aim of my project is to identify and model the interaction between the main drivers of urban economic segregation in order to assess and compare remediatory policies at three geographical scales: national, urban and individual. It addresses the research gap relating to the spatial distribution of economic groups between and within cities in contexts of rising inequality, as well as the question of why public policies applied at city-level (for instance, housing mix or transportation programs) fail to reduce economic segregation. Three more specific objectives are pursued and detailed below:

1. to uncover the theoretical interactions between the urban, national and individual processes which lead to urban economic segregation.
2. to animate this combination of explanatory processes of urban economic segregation using simulation modelling.

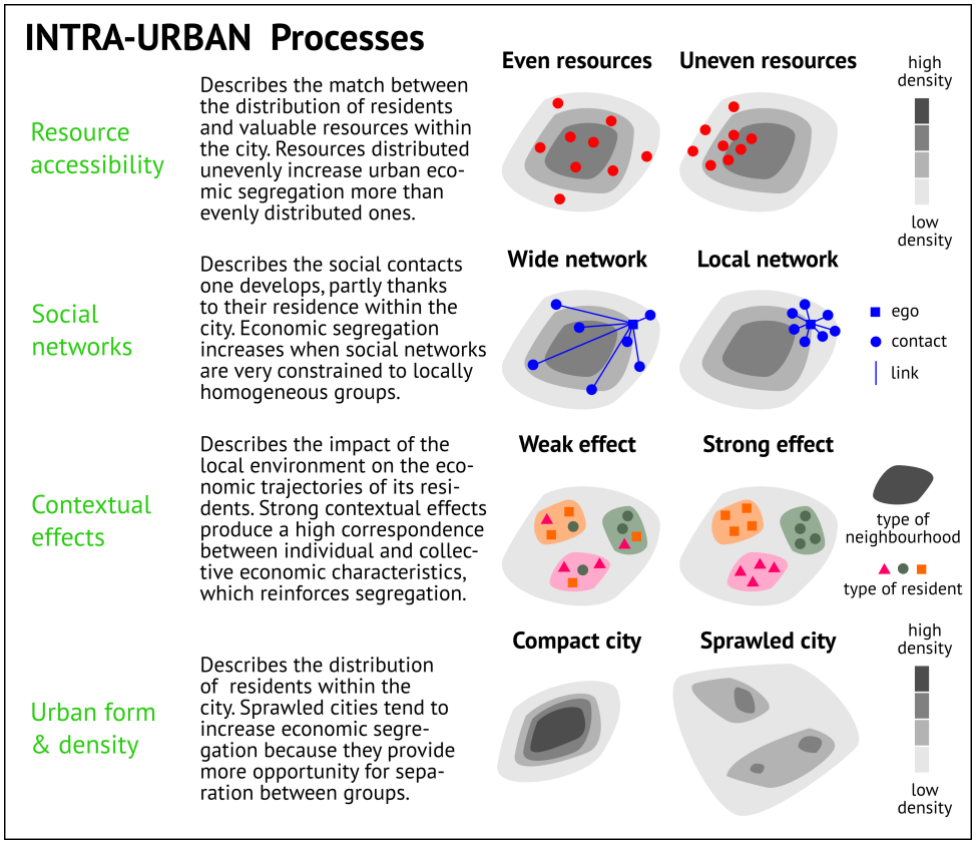
3. to use the model of urban economic segregation to develop, compare and assess policy scenarios of segregation reduction.

In the following paragraphs, I review the existing research available and how each of my research objectives will allow to push research forward and break new grounds in the understanding, modelling and reduction of urban economic segregation.

Overarching aim: to identify and model the main drivers of urban economic segregation.

Within the traditional literature, understanding the dynamics of urban economic segregation has been done mainly **within city boundaries.** Massey & Denton (1988), in their famous review of segregation measurement, identified five dimensions worth considering to describe segregation patterns: evenness ("*the differential distribution of two social groups among areal units in a city*" p. 283), exposure ("*the degree of potential contact, or the possibility of interaction*" p. 287), concentration *("[the] relative amount of physical space occupied by a [...] group in the urban environment*" p. 289), centralization and clustering. These dimensions correspond to specific processes explaining the (re-)production of economic segregation: the uneven access to urban resources (resource accessibility), the exposure to homogamous or diverse social contacts (social networks), the concentration of urban dwellers in given environment (contextual effects), their relation to density and to the wider geography of the city (urban form). These processes are represented in Figure 1.

Figure 1. Theoretical processes of urban economic segregation within cities



Accessibility to urban resources – from fresh healthy food stores to higher education and cultural heritage – influences individuals' decisions to settle in particular places, but also impacts daily life through the time and cost spent finding and accessing such resources, or even renouncing them in the case of preventive medicine or healthy nutrition (Vallée et al., 2010; Auchincloss et al., 2011). Because the rich can always, by definition, outbid the poor on the housing market, the spatial distribution of wealthy households tends to correspond in the long run with the distribution of the urban resources they value most (Boeing, 2019). "*Moreover, this process is inevitably self-reinforcing as richer inhabitants improve precisely those local amenities they value, so making their neighbourhoods more attractive to other richer people*" (Cheshire et al. 2014, p.65). This is therefore one channel through which urban economic segregation comes about and is reproduced.

Social networks matter in the evolution of urban economic segregation because the nature and types of social ties one builds and develops with peers depends partly on the composition of one's local environment. These ties can later influence the economic trajectories individuals experience, i.e. their future job prospects (Granovetter, 1973) and future income, but also their social capital (Bourdieu & Passeron, 1970). As a

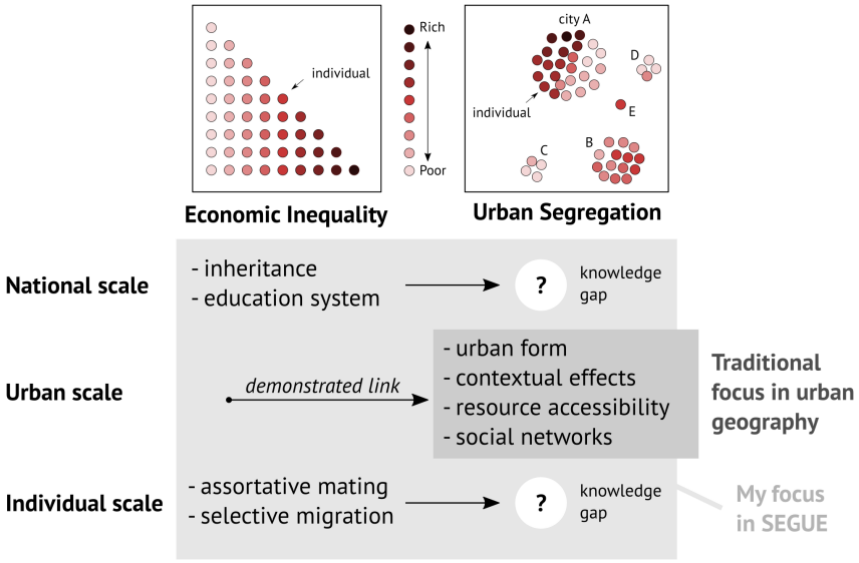
consequence, *"[in Swedish cities,] there are generally significant effects of the area compositions [like the share of low-income households] on individual income, at all scales"* (Andersson & Muster, 2010, p. 35). Therefore, moving to a different neighbourhood can affect an individual's role models, representations and behaviours through the social network they interact with locally on a daily basis (Wilson, 1987 ; Galster, 2012; Sampson, 2012). The exposure to one's local environment and local institutions (schools, clubs, political governance) can be another explanation for why individual outcomes of similar people differ when they grow up (Chetty et al., 2014), move to reside in (Hedman & van Ham, 2012) or frequently visit (Vallée et al., 2010) different neighbourhoods.

Contextual effects reflect this aspect: geographical environments impact people's economic trajectory, i.e. what they go on to earn and own in the future (Chetty et al., 2014). According to the proponents of contextual effects, cities and neighbourhoods are far from neutral recipients of economic agents in cities. "*If the spatial context of daily living has an effect on the subjective experience of poverty, then what it means to be poor has changed for the worse in recent decades. In the vast majority of cities, the poor were increasingly isolated from the mainstream of society in high-poverty ghettos and barrios"* (Jargowsky, 2002, p. 43). The environmental effects of segregated cities and neighbourhoods range from pollution to insecurity and low incentives for physical activity, etc. Such factors might have a long-lasting effect on individual's economic trajectories as well as on the reputation of places.

Urban form and density have been shown to influence economic segregation (Wheeler, 2006), in the first place because house prices tend to be strongly correlated with urban density (high density meaning higher prices in European cities, and the opposite in North American cities). Secondly, "*sprawl creates a greater degree of separation between the income classes*" (Jargowsky, 2002, p.51), just like fractal urban structures create more opportunity for clustering and separation between urban groups, regardless of the social processes at work (Banos, 2012; Raimbault et al., 2019).

So far, the urban segregation literature has been too often limited to processes which happen within city limits. This has two consequences. Firstly, it means that the study of the allocation of economic groups between cities (through selective migration and economic trajectories) has been neglected in the study of urban segregation, which leaves a gap in how we understand and consider the economic composition of cities in the first place. Secondly, it means that the drivers of segregation targeted by urban planners and policy makers have been limited to the city level (the local housing market and urban transportation mostly). **However, the causes of urban economic segregation are neither all geographical nor all limited to the city boundaries. Some drivers of inequality at the national scale and at the individual scale can also affect where economic groups settle in cities, and therefore the level of urban economic segregation in various cities** (cf. figure 2). The spatialisation of these drivers of segregation constitute a knowledge gap which I aim to reduce.

Figure 2. Theoretical drivers of economic inequality and urban segregation by geographical scale



Morgan (1975) did identify the need to conduct further research on urban segregation "*at three levels: (a) The regional and national level [...] (b) The level of the individual town [...] (c) The level of the individual household*" (p.59) more than forty years ago, but his call does not seem to have been heard. I propose to build on this idea and to specify this program by linking these three scales with the processes of (re)production of

economic inequality usually out of the scope of urban segregation studies. I argue that knowing how economic inequality is produced (what makes the economic composition of population in cities and regions in the first place), reproduced (why do individuals, households and families get richer or poorer?) and spatialised (how are individuals from various economic groups allocated spatially?) matters to the understanding and modelling of urban economic segregation. Since these questions have remained unanswered until now in the urban segregation literature, my project will break new theoretical grounds by accounting for processes which take place beyond the individual city (at the national scale) and within social groups (at the individual level), i.e. where economic inequality is produced, reproduced and spatialised.

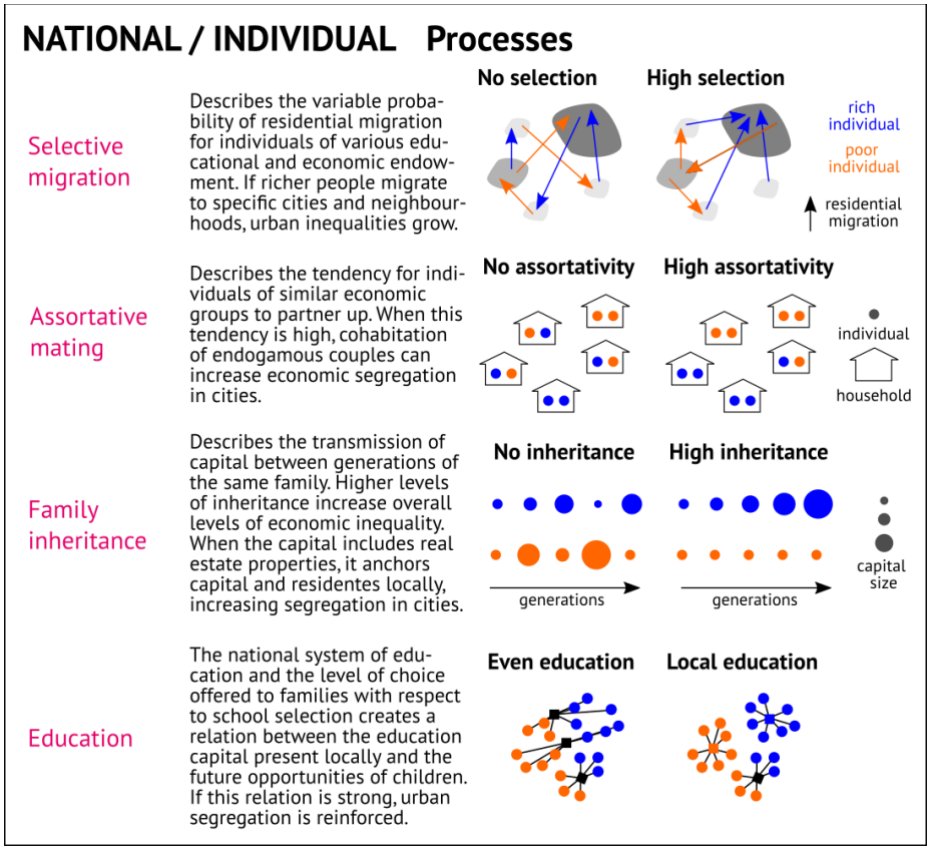
1st objective: uncovering the theoretical interactions between the processes of urban economic segregation at various scales.

The additional processes of economic inequality affecting urban segregation fall into two categories: national drivers of economic inequality and individual factors of inequality reproduction, represented in figure 3.
At the national scale, I will build on the large **literature documenting the evolution of economic inequality** (Piketty, 2013; Atkinson, 2015) and its causes (Alacevich and Soci, 2017). These studies highlight the importance of institutional structures (health and education systems, tax system, legal system, trade and globalisation) in determining the distribution of income and wealth and their evolution in society, because these factors of economic inequality translate into economic segregation in cities. "*Higher income disparities and more liberal forms of welfare regime bring about higher levels of segregation but the relationship is not simple"* (Musterd et al. 2017, p.1077). The spatial distribution of the national income and wealth remains a blind spot of the economics literature (Piketty, 2015). Some studies have started to address the specific factor of city size at national levels. Morgan (1975) found a linear positive relationship between the residential differentiation index for socioeconomic groups and the logarithm of city size in Wales. This type of relationships has met renewed interest recently under the label of "urban scaling": Sarkar et al. (2018) show that individuals from higher income deciles are disproportionately concentrated in larger Australian cities, whereas individuals with lower incomes are distributed in proportion to city population or concentrated in the smaller cities. In my own work, I have identified a similar pattern for France, where the levels of wage inequality increase with city size regardless of the city definition chosen (Cottineau et al., 2019a). A recent study confirmed this trend for the United States (Mora et al., 2021). I will therefore add to the existing literature by explicitly linking the national changes in inequality to changes in urban composition, which then affects urban segregation, considering where the changes in economic inequality take place, based on city size and urban form, but also based on the relationship between regional and urban labour and housing markets.
At the individual scale, I will build on the literature on non-spatial processes like the **intergenerational transmission of wealth via inheritance and via the transmission of educational, cultural and social capital** (Bourdieu & Passeron, 1970; Hertz et al., 2008), but also **assortative mating**, i.e. the tendency for persons of similar economic profiles to partner up (Schwartz, 2013). However, I will innovate by considering how these individual processes of inequality reproduction take place in particular locations, and in particular homes, since the transmission of wealth and the composition of households combine on the housing market to allocate families to particular residential locations. Furthermore, assortative mating implies that individuals enter in contact and meet in order to partner up, therefore it suggests that individuals have elected residence in particular cities, in particular neighbourhoods, or have similar patterns of daily mobility which affect the spatial distribution of income and wealth. At the individual level, people with different education levels have different economic and geographical trajectories. In Sweden for instance, the most educated individuals are more likely to leave small cities and regions not densely populated, and to join large cities and populous regions in Sweden (Keuschnigg et al. 2019). Selective migration has been shown by Bailey (2012; et al., 2017) to combine with *in situ* economic mobility to change the level and patterns of socioeconomic segregation in Scotland and the Netherlands. Indeed, residing in a particular place can change the socioeconomic status of an individual. This process is documented for the London region[1], which works as an *escalator* (Fielding, 1992), since each year spent working in London confers an economic advantage to the worker compared to its counterpart outside London, and as an *elevator* (Gordon et al., 2015), since the move itself to the capital provides a one-off increase in average income for the individual concerned. Processes playing at the individual level of life trajectories affect both the total income distribution at the national level, its spatial distribution between cities and regions, and the composition within the places of departures and arrival of residential migrants.
Although these individual processes are getting better documented empirically and theoretically, there is a real knowledge gap in understanding their **interaction**, mostly because they are studied at different scales. For

[1] Testing this hypothesis for other cities, in particular in the Netherlands, will be an added benefit of this project.

instance: how does assortative mating interact with urban density or with migration to escalator regions to increase urban inequality and segregation? Is there a scaling pattern in the individual trajectories of economic inheritance resulting in higher urban inequality and segregation? Is increasing economic inequality associated with more unevenness in the distribution of urban resources (and therefore with less accessibility)? These questions will be first addressed empirically by the exploitation of Dutch register data (cf. Work Package 2).

Figure 3. Theoretical processes of urban economic segregation at the national or individual scales



2nd objective: to "animate" this combination of explanatory processes of urban economic segregation using the frontier technique of agent-based simulation.

Research in social sciences (Epstein & Axtell, 1996; Manzo, 2014) has demonstrated the benefit of using generative modelling (i.e. the implementation of rules of action whose consequences are simulated by a computer) in complementarity with statistical modelling to explain social phenomena. The most radical tenants of the generative explanation even claim that "*if you didn't grow it, you didn't explain its emergence"* (Epstein, 1999, p.43). Most often, sociologists and geographers agree that statistical models are most useful to describe empirical associations between variables (Goldthorpe, 2001), that model-building with generative mechanisms reflecting "middle-range theories" produces a causal explanation of how a phenomenon is produced (Hedström &. Udehn, 2009), and that simulation is most able to animate this explanation and to dynamically test the theoretical mechanisms selected[2] with respect to their ability to reproduce empirical patterns (Manzo, 2014). Mechanisms in that context refer to theoretical implementation of empirical processes. According to Machamer et al. (2000, p.3), "*to give a description of a mechanism for a phenomenon is to explain that phenomenon, i.e., to explain how it was produced"*. I argue that it is rather the exploration of its simulation and its confrontation with empirical data which allows to explain urban phenomena (Pumain and Reuillon, 2017) as well as to develop existing theories (Lorscheid et al., 2019). The model I aim to build from the combination of explanatory processes of urban economic segregation at different geographical scales is a generative and multiscale agent-based model. It combines in a modular structure various mechanisms of urban economic segregation, which represent partial theories at different scales. Its structure (the combination of mechanisms) and parameters will be calibrated with individual data from the Netherlands, but the model itself will be replicable to analyse other national cases studies in the future. For these reasons, it represents a ground-

[2] in this case: mechanisms translating the eight processes of urban economic segregation at the urban, national and individual scales.

breaking addition both to the study of urban segregation and to the field of geosimulation models. It will also bring a tool on which to implement and compare alternative policy scenarios of segregation reduction.

3rd objective: to use this integrated model of urban economic segregation to analyse and compare policy options for segregation reduction.

The advantage of developing an integrated model of urban economic segregation is that it allows to conceive, test and compare remediatory policies at various geographical scales to reduce economic segregation in cities. Several types of public policies will be implemented as scenarios and compared: mixing policies through residential and renewal subsidies (Clarck & Everaers, 1981), residential relocation (e.g. de Souza Briggs et al., 2010), transport and accessibility policies (e.g. Yang et al. 2015), income and wealth tax (e.g. Piketty, 2013), education policies (Solga, 2014), or combination of place-based and people-based policies (Manley et al. 2013; Cheshire et al., 2014). An exercise of policy assessment within a virtual laboratory provides a "low-cost" solution compared to "real-life" experiments. Scenario analyses with agent-based models are now a recognised first step towards policy recommendations against urban segregation (Bernard, 1999; O'Sullivan, 2002; Torrens & Nara, 2002; Auchlincloss et al. 2011; Boeing, 2019). My innovation with this project will be to provide a *multiscale* comparative analysis of policies, which does not exist at present for urban economic segregation.

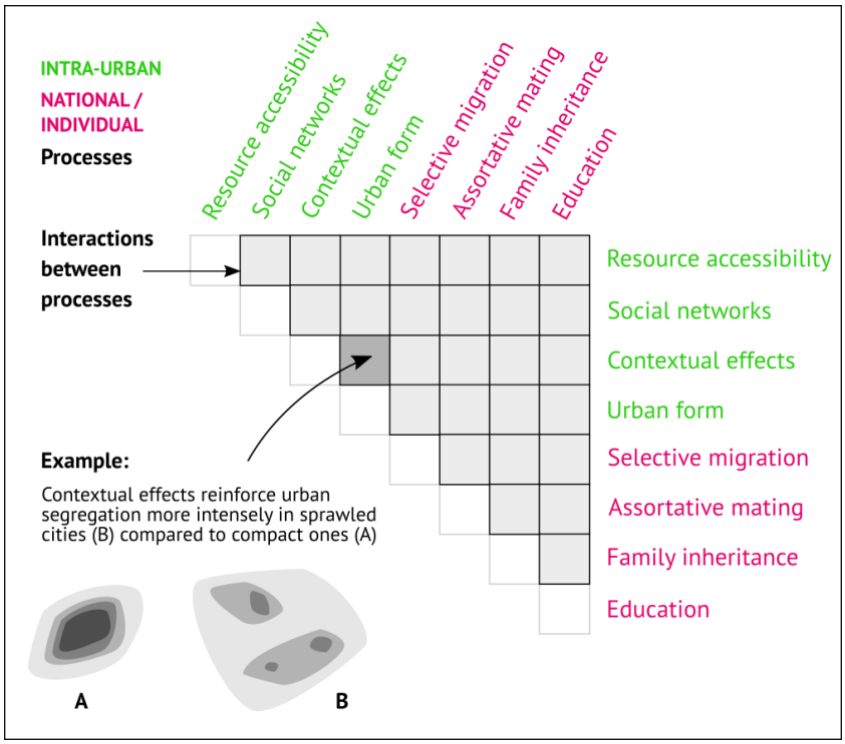
> SUMMARY: the existing literature on urban segregation mainly explains urban economic segregation with sociological and intra-city factors (resource accessibility, social networks, contextual effects and the urban form) but also acknowledges a link with the evolution of economic inequality. The existing literature on economic inequality, by contrast, mainly focuses on factors operating at the national and individual levels (selective migration, assortative mating, family inheritance, education). My project will break new grounds by spatialising the national and individual explanations of economic inequality relating to residential mobility or the tax and education system, and by integrating these into a single model of urban segregation. Its animation through simulation will lead to new theoretical insights about the interaction between mechanisms as well as to a cost-effective way to compare policies to reduce urban economic segregation at different scales of action (local, urban, national).

Section b. Methodology

Approach and methods.
My approach to achieve this ambitious program can be decomposed into *four* methodological phases.

1. The first methodological phase of the project consists in selecting and analysing the potential explanatory mechanisms of urban economic segregation and spatialised urban inequality. At the moment, I have identified four intra-city processes driving urban economic segregation (resource accessibility, social networks, contextual effect and the urban form, cf. figure 1) and four non-urban processes driving economic inequality which have consequences for urban segregation (selective migration, assortative mating, family inheritance and the reproduction of human and social capital through education, cf. figure 3). These processes have to be unfolded and analysed in detail with respect to the type of actors involved, their temporality, the scale at which they operate and the indicators and proxies which can be used to represent and test them empirically. Secondly, in preparation for the simulation model-building, my team and I will explore the interactions between these processes in theory (cf. figure 4). For each of the 8 x (8 - 1) / 2 = 28 pairs of processes, we will work towards a theoretical deduction of the effect of their interaction, based on the literature available. Two processes can cancel each other, reinforce one another or be independent with respect to their impact on urban economic segregation in a given context. For instance, the importance of contextual effects can be reinforced by certain urban forms and attenuated by others: there are more opportunities for mixing outside of one's neighbourhood in a dense city compared to a sprawled one, especially for younger residents (Lee et al. 2008). In the first case, the two processes will combine to produce higher segregation whereas in the second case, urban form can compensate contextual effects to some extent (cf. figure 4). This systematic approach to process interactions is very original in the field of urban segregation. I am not aware of any equivalent research design.

Figure 4. Exploring the interactions between theoretical processes of urban economic segregation



2. The second methodological phase of my approach consists in testing empirically the relevance and importance of each driver of urban economic segregation. Each process and pair of processes will be examined using empirical data. The type of data needed to fulfill this goal is very demanding: it needs to describe individuals, their economic situation (income and wealth), their residential location, over time. Furthermore, this data should also provide proxies for the various factors affecting economic inequality and segregation, such as family ties, education levels, residential migration history, etc. Ideally, we could also make use of indications about preferences and opinions, as well as a depiction of social networks, professional and friendship ties, but these are out of reach in systematic longitudinal and exhaustive surveys. Besides, our empirical case study should offer a representative view on current processes of urban economic inequality, cover a significantly large population (i.e. over 10 million inhabitants) located in a diversity of city types (i.e. not just a capital city and smaller towns), over at least a generation (i.e. approximatively 20 to 25 years). Ideally, we would opt for a comparative analysis of two countries of similar size, but with opposite levels of wealth concentration, for instance South Africa and Italy (~60 million inhabitants each, South Africa's top 10% people bringing home twice the share of national income of Italy's top 10% in 2010, i.e. 60% vs. 30%) or Chile and the Netherlands (~between 17 and 19 million inhabitants, respectively 56 and 28%)[3]. Unfortunately, few sources of data fulfil our core requirements (individual, longitudinal, spatial, economic) on an exhaustive population. Indeed, this type of data is quite unique, and gathered at present only in small and rather egalitarian countries (Denmark, Sweden and the Netherlands)[4]. The optimal case study I have identified is the Netherlands, which provides access to their register to accredited researchers. It has a larger population than Denmark and Sweden, a higher level of wealth inequality (despite a relatively low-income inequality) and its spatial organisation is more interesting for this project, with a contrast between the Randstad and more isolated cities in the North and East of the country. The Dutch Statistics Bureau (CBS) allows researchers to draw from individual social statistical databases (SSD) made from register data, i.e. administrative data collected by municipalities and national agencies on the ±14 million adult residents of the Netherlands. Individuals in this database are located very precisely on grid cells of 100m x 100m based on their residential address[5]. Educational and fiscal information can be merged to this database using a single anonymised identifier. Economic records regarding integral income and wealth can therefore describe individuals and households[6]. The economic set of data is accessible since 2011, yet the spatial and family information is available[7] since

[3] https://wid.world/data/
[4] although it seems like more countries will be opting for a more similar setup in the future, with more individual information accessible in a secure environment, more links between census and administrative data and more flexible location attributes.
[5] https://www.cbs.nl/nl-nl/onze-diensten/maatwerk-en-microdata/microdata-zelf-onderzoek-doen/microdatabestanden/vslvierkanttab-coordinaten-vierkanten-verblijfsobject
[6] https://www.cbs.nl/en-gb/our-services/methods/surveys/korte-onderzoeksbeschrijvingen/integral-income-and-wealth-statistics
[7] https://www.cbs.nl/nl-nl/onze-diensten/maatwerk-en-microdata/microdata-zelf-onderzoek-doen/microdatabestanden/gbapersoontab-persoonskenmerken-van-personen-in-de-brp

1995. The project will therefore focus on this case study but will explore the possibility of reproducing results and using the models on other national case studies with less fine-grained data and more wealth concentration (Chile for instance). **This source of data is unique at this scale and I have been able to assess its usefulness for the project by working with individual migration and income data since 2020**. Indeed, remote access to CBS data through a secure environment is possible after clearance and with a fee. I have experience with using this setting as well as similar ones in the UK and France, and so do my colleagues at the Urbanism department in TU-Delft, a centre of expertise for Dutch register data in relation to segregation research. This distinctive concentration of data and expertise is the main reason why I relocated from CNRS in France to TU-Delft in 2020. The three recruits on the SEGUE project (two PhD students and a post-doctoral researcher) will request clearance from CBS[8] and a part of the project funding will be allocated to paying data access fees and quantitative methods training. This investment is needed to validate the theoretical hypothesis about the importance of processes of urban economic segregation and their interaction at various scales.

3. The third methodological phase of the project consists in building a modular and incremental agent-based model of urban segregation, made of the most relevant mechanisms suggested by the first two phases of the project. The generative modelling approach complements the statistical modelling approach of the previous steps. Instead of looking for correlation in the data, my team and I will suggest explanations (or middle-range theories, presented above as processes of urban economic segregation) for the observed evolution of economic urban segregation in the Netherlands, translate them into generative mechanisms and run the simulation to see if they result in a similar configuration to that observed empirically. This phase of the project relies on my recognised experience with building and analysing agent-based models of urban evolution (Cottineau et al., 2015a) and social segregation (Cottineau et al., 2018). It will also rely on the methodology of incremental modelling which I co-developed (Cottineau et al., 2015b; Cottineau et al. 2019b), i.e. an innovative way of building agent-based models which combines several mechanisms into one (modular) model while retaining the possibility to activate or deactivate them to assess each mechanism's contribution to the final output simulation. This methodology will be applied here to a completely new modelling challenge: a multiscale model. Multiscale models of urban dynamics are themselves still in their infancy (Raimbault, 2021). "*They brings out a number of fundamental problems, such as: (1) the preservation of a population during transfers between the macroscale (rational numbers) and microscale (whole numbers); (2) the inclusion of a population considered as homogeneous in the aggregated model components and of heterogeneous individuals in its disaggregated components; (3) the articulation of different scales of time and space, handling for example the spread of an epidemic at a city level and the traveling behavior of individuals; and (4) the characterization of the behavior of the global model and its properties, which cannot be reduced to the properties of each of its components*" (Banos et al., 2015, §1). The first two challenges will be mitigated by the access to exhaustive empirical data on individual trajectories (unlike Banos et al., 2015). It will thus be possible to characterise the composition of populations at the scale of each city and the order of magnitude of residential migrations from one to another over the past ten years. The problem of the articulation of scales of time and space will be prepared earlier in the project by the attention given in the first phase to each process and its interaction with the others. The characterization of the behaviour of the global model and its properties will be an important task for this phase of the project.

4. The fourth and last methodological phase of the project is the representation of alternative policy scenarios in the model and the comparison of their simulated effects on urban economic segregation within the calibrated model. Policy scenarios correspond to classical policy response to urban economic segregation: residential mixing, transport accessibility, wealth redistribution, inheritance taxation. These scenarios will be compared with one another in terms of simulated effectiveness, cost and side-effects. Simulation models are by definition based on simplified abstractions of reality, but policies must be able to mitigate the complexity and messiness of reality. Our task will therefore be to also consider the representation of this "messiness" in policy scenarios and the margins of negotiation between the simulation and actual implementations. This last phase of the project will then transform the academic agent-based model grounded theoretically and empirically into a cost-effective tool for policy evaluation, thus reaching this project's third research objective.

Workplan.

The four methodological phases of the project will be ventilated into seven work packages (cf. table 1):

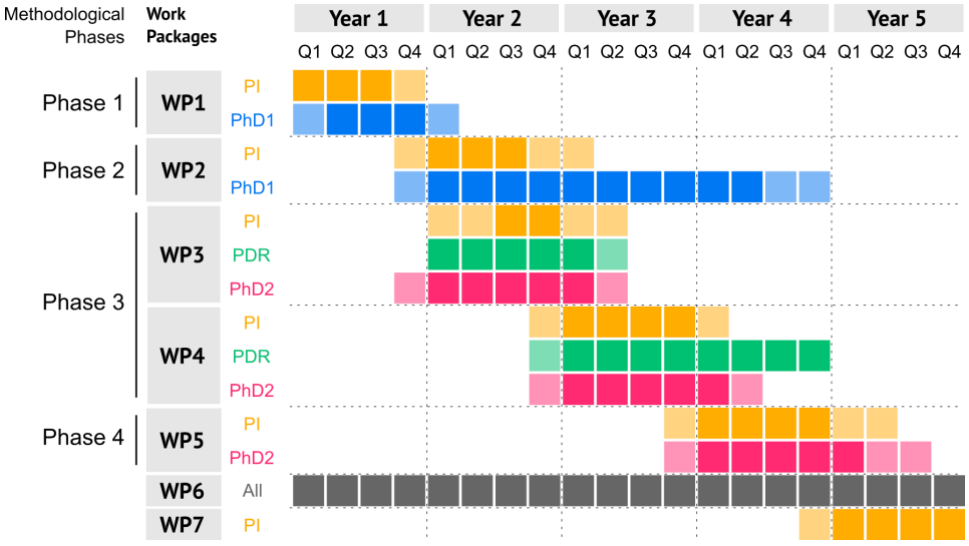
- The first work package (WP1) tackles the theoretical analysis of potential explanatory mechanisms of urban economic segregation and their interaction across scales.
- WP2 addresses the empirical evaluation of each process by examining longitudinal Dutch register data.

[8] I already have the status of accredited researcher with CBS and have been working with Dutch secure microdata data since 2020.

- WP3 will be dedicated to model-building.
- WP4 will be dedicated to the evaluation and exploration of the simulation model containing competing candidate mechanisms to explain the evolution measured empirically.
- WP5 is the implementation and comparison of various policy scenarios to reduce urban economic segregation in terms of efficiency, cost and side-effects within in the evaluated model.
- WP6 will ensure the reproducibility of the methods (including documentation of the code) and explore the reproducibility of the case study to other national contexts.
- WP7 will deal with the synthesis and dissemination of the final results of the project.

Each work package is described below with respect to the tasks included, the planning (table 1) and role of each member of the project team. This core team will consist in me as PI, two PhD students (PhD1 and PhD2) and a post-doctoral researcher (PDR) recruited on the project. We will work in close collaboration with the Urban Studies section of the Urbanism Department at TU-Delft, which has a long experience in working on urban inequality with CBS microdata, and in particular with a PhD student working under my supervision on the empirical analysis of residential migration in the Netherlands.

Table 1. Exploring the interactions between theoretical processes of urban economic segregation.



WP1-Theoretical integration.

WP1 will be conducted by myself as PI and by the PhD1 during the first year of SEGUE. Our tasks will be:

- to organise and extend the preliminary literature review present in this proposal.
- to select the explanatory mechanisms of urban economic segregation and spatialised urban inequality to include in the study. Four potential processes of urban economic segregation are already identified at city level: resource accessibility, social networks, contextual effect and the urban form. Four potential non-urban processes of economic inequality are already identified because of their consequences on urban segregation: selective migration, assortative mating, family inheritance and the reproduction of human and social capital through education.
- to analyse their compatibility systematically by identifying which actors are involved (individuals, households, families, schools, neighbourhoods, etc.), what is the range of their action in space and time, as well as the statistical proxies available measure them.
- to explore the interactions between the pairs of processes.
- to summarise and discuss our results with peers through informal interactions, seminars and publications in the urban inequality community.

WP2-Empirical evaluation.

WP2 will be conducted by the PhD1 under my supervision. The tasks will be:

- to get the accreditation from CBS to access Dutch microdata (only for the PhD1 - I am already accredited).
- to organise the architecture of the different datasets, through table joints and a relational database. For instance, the residential history of Dutch residents is available in one dataset (GBAPERSOONTAB), their education level in another (HOOGSTEOPLTAB) and their income yet in a different one (INPATAB). There is however a way to link the various tables together through anonymised individual identifiers.
- to construct relevant proxies from the raw data and to compute the levels of urban economic segregation in all parts of the Netherlands over time.

- to test the significance of the selected process and their interactions, using statistical modelling, from linear and multilevel regression with fixed effects and interactions to geographically weighted models, path model analysis and structural equation modelling depending on the final structure of the measures and data.
- to identify the most significant and relevant processes/interactions to implement in the agent-based model for the next phase of the project.
- to summarise and discuss our results with peers through informal interactions, seminars and publications in the urban studies community.

WP3-Model building.
Building on theoretical assumptions (WP1) and empirical insights (WP2), WP3 will focus on the generative processes of urban economic segregation rather than on statistical covariations. A PDR experienced in agent-based modelling and a social science PhD2 interested in simulation techniques will be recruited to conduct this work package's tasks under my supervision, from the second year of the project. Their first task will be to get the accreditation from CBS to access Dutch microdata. Their access to the empirical microdata is crucial for the initialisation and evaluation of the model. Indeed, the model will rely on a synthetic population of the Netherlands, calibrated on the empirical population in 2011. The model will then simulate the evolution (i.e. its residential migrations between and within cities of the Netherlands, individual economic mobility and household dynamics) of this population month by month for the equivalent of ten years, at which point the simulation is compared to significant patterns of the empirical population in 2021. The PhD2 will work in tandem with the PDR to translate theoretical processes of urban economic segregation into a functioning computer program representing the Dutch population, using the Agile method of software development. The PDR will be responsible for the fact that the code implemented does what we intend it to do (model verification) whereas the PhD2 under my supervision will be responsible for the mechanisms implemented to represent the social processes observed empirically (model validation). The PDR's extra task will be to build a modular architecture for the model to run with or without each of its mechanisms, in the spirit of incremental modelling (Cottineau et al., 2015a; 2019b). They will find assistance through a collaboration with confirmed computer scientists and modellers Julien Perret and Romain Reuillon from the Complex Systems Institute (CSI) in Paris, who have agreed to collaborate respectively on the initialisation of the model and on its modularity. This collaboration will take the form of regular online meetings between the SEGUE team and CSI collaborators, as well as an intensive coding camp towards the end of the second year. This event will be funded by the SEGUE budget and is expected to facilitate the collaboration and advancement of the model.

WP4-Model exploration.
WP4 will be conducted by the same team as WP3. Our tasks will be:
- to test the sensibility of the model to changes of its parameters and initial spatial conditions (Reuillon et al., 2015; Grimm & Berger, 2016; Raimbault et al., 2019). The SEGUE project members will be assisted in this task by a sub-contractor specialised in high-performance computing for simulation model analysis, in particular sensitivity analysis, robustness analysis and model calibration.
- to explore the limit cases the model can produce through an extensive search of the output space of the model, as in Chérel et al. (2015).
- to identify the combination of mechanisms which reproduces best the evolution of urban economic segregation observed in the Netherlands as a whole, and in each city in particular. This corresponds to a calibration of the structure of the model as well as a calibration of its parameters (Cottineau et al., 2015).
These first three tasks will make use of the new TU-Delft supercomputer to reduce computation times.
- to summarise and discuss our results with peers through informal interactions, seminars and publications in the social and geographical ABM community.
- to share our new knowledge with young researchers through a summer school in urban simulation. This event will be funded with the project budget, and is expected to produce two outcomes: to enhance the production of teaching material from our research and to disseminate innovative modelling practice to the future generations of urban modellers.

WP5-Policy testing in silico.
WP5 will be conducted by the PhD2 and myself. Our tasks will be:
- to review existing and theoretical policies to reduce urban economic segregation and economic inequality.
- to implement them as scenarios in the calibrated simulation model.
- to assess and compare results between different scenarios.
- to summarise and discuss our results with peers through informal interactions, seminars and publications in the urban studies, policy evaluation and ABM communities.

- to share our new knowledge with policy analysts and decision-makers through a dedicated workshop. This event will be funded with the project budget, and is expected to test the applicability and reception of our research results on policy makers.

WP6-Reproducibility.
This package is included in the project to ensure two types of reproducibility. The first one concerns the aggregate data, methods and code used for the data analysis, model building and model exploration. It seems important to decide from the start to dedicate enough time, thought and resources to the development of perennial repositories for documented code, aggregated data and metadata. This will foster the curation and preservation of know-how, facilitate the re-use of data, methods, and models developed, and guarantee the transparent communication of scientific results in publications and other forms of dissemination (such as perennial submission of aggregated datasets on the institutional public portal 4TU.Centre). A Data Management Plan will be drawn along with a TU Delft's data steward within the first 6 months of the project. The second aspect of this work package is more exploratory and will concern the reproducibility of the case study to other national contexts. We are not aware at present of other national contexts to which our analysis and modelling will be directly applicable because of the current lack of adequate data. However, within WP6, we will explore the possibility of replicating analyses to other contexts: similar contexts where we can test the applicability of the methods on less fine-grained data, and interesting contexts for comparison (Chile for instance). All participants to the project will contribute to the reproducibility package throughout the project.

WP7-Synthesis.
During the final year of the project, I will prepare a synthesis of the work done and the results produced, along with their dissemination (including a book of synthesis published in open access).

Teams and roles
The project will be completed in five years with the contribution of two PhD students and one post-doctoral researcher. The PhD1 will be the main contributor to the WP2, i.e. the empirical evaluation of theoretical processes of urban economic segregation. The PhD2 will be the main contributor to the WP3 and 5, i.e. the development of the agent-based model of segregation and the comparison of policy scenarios. They will be assisted by a PDR in computer science for 36 months, the main contributor to the WP3 and 4, i.e. the implementation and exploration of the model. Additionally, the team will find support within the department of Urbanism at TU-Delft and through scientific collaborations within my international professional network, namely within the Complex Systems Institute in Paris, the Centre for Advanced Spatial Analysis in University College London and the ABM theory group in Germany.

SUMMARY: The main originality of this workplan is its integration of theoretical processes of urban economic segregation across scales and disciplines through individual-based simulation. This is made feasible by the complementarity of skills in the project team, the availability of micro-data in the Netherlands and high-performance computing at TU-Delft. A significant novelty of my methodological plan lays in its reproducibility thanks to the modular structure of the model. This way, the model is calibrated to represent the economic evolution of the Netherlands and their cities, but it can be adapted to further case studies by adding, removing or modifying blocks of mechanisms. Finally, the comparison of policies at different geographical scales is an innovative take on policy evaluation to reduce economic segregation in cities.

Risk, reward & feasibility
The project runs one main risk: the curse of dimensionality. A challenge of multiscale agent-based models is indeed their large size and the amount of time and computing resources needed to run and explore them. The presence of a dedicated centre and staff for high performance computing at TU-Delft (www.tudelft.nl/dhpc/), the introduction of a new supercomputer in 2021, the budget allocated to server space and the expertise contributed by a subcontractor will help mitigate this challenge and ensure that a thorough exploration of the model will enable us address the second research objective of this project: to animate this combination of explanatory processes of urban economic segregation using the frontier techniques of agent-based simulation. Through the combination of alternative, competing and complementary explanations to the evolution of urban economic segregation, we will run the risk of creating a theoretical framework and a simulation model in which the contribution of each factor and each process cannot be properly disentangled due to equifinality (i.e. the principle that a system's end state can be reached by many potential routes, or by the action of different mechanisms in our case). Regarding the theoretical framework, we will mitigate this risk by analysing each

interaction in detail, to identify the unique signature of two processes playing alongside, even when they compensate each other at one scale. Regarding model comparison and selection, we will mitigate this risk by exploring the model extensively with original and cutting-edge methods I have contributed to develop (to analyse the possible outcomes generated by a model: cf. Chérel et al., 2015; to calibrate a multimodel structure alongside its parameter values: cf. Cottineau et al., 2015b; to account for the influence of initial spatial conditions on the model outputs: cf. Raimbault et al., 2019) and by developing new ones (to explore, calibrate and compare model structures whose modules operate at different scales) with my collaborators and leading partners in the field. Such original methods are unique in the young and developing field of agent-based and much needed for multiscale models.

Output and dissemination

The project is expected to produce two PhD theses, documented codes and models made available under open-source licenses, a summer school on urban inequality, an international workshop on segregation policies, as well as several academic publications in scientific journals and a book of synthesis. The SEGUE project members will also present their results at international conferences, during in research seminars and more informal research meetings. It should enhance the team members' expertise in urban inequality and geosimulation, their processional networks and recognition in the field. Dissemination will also be directed towards a larger audience, through the constitution of a website, media and social media interventions.

Expected Impact

The successful development of the SEGUE project should lead to a better understanding of urban economic segregation, not only at the scale of one city but as a systemic phenomenon affected by macro-trends of economic inequality as well as micro-dynamics of families and individuals. It should equip this understanding with a tool to animate the evolution of urban economic segregation in the Netherlands and compare remediatory policy scenarios. This tool (the simulation model) is designed to be reproducible, i.e. scientifically sound, but also reusable in other national contexts and by other research teams. The project's results will bring the geographical, economics and sociological approaches of urban segregation closer together, by demonstrating the interdependency of scales and processes favoured by each of them. **The better understanding of urban economic segregation and the modelling tool developed will allow my team to advise policy makers on the efficiency and side-effects of alternative policies to reduce urban segregation *ex ante*, that is without having to experiment *in situ*, which saves from potentially putting real lives at risk and spending public money inefficiently.** New questions should also arise, regarding for instance transferability of our results to other forms of inequality and segregation, as well as to other national contexts.

SUMMARY: this project will make use of frontier quantitative and simulation methods to test and animate a strongly grounded theoretical framework. The main risk of the project (creating alternative, competing and complementary explanations to the evolution of urban segregation which cannot be properly disentangled due to equifinality) will be mitigated by exploring the simulation model extensively with cutting-edge methods. This project should bring about a whole new approach to urban economic segregation: one that is integrated, multiscale, quantified and operable through a simulation tool oriented towards policy evaluation.

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Part A.

Section C. Resources (Maximum 8000 characters allowed)

A total budget of 1 495 125 euros is necessary to fulfil the research objectives of my ERC project SEGUE. Two thirds of this budget consist of direct research personnel costs (A). The rest of the resources is allocated between subcontracting costs (B) and purchase costs (C). These correspond to the costs of access to research inputs (data, equipment, training and expertise); the costs of disseminating the results obtained through the project, in three forms: 1/ scientific publications, 2/ conferences and seminars, 3/events organised at TU-Delft; and the costs of a financial audit. Finally, indirect costs amount to 275 625 euros.

A. Total personnel costs = 984 900 euros

The realisation of the scientific program described in B2 relies on the contribution of the PI, two PhD students and one postdoctoral researcher. As PI, I will allocate 70% of my time to the ERC project (the other 30% being dedicated to education and service at the Faculty of Architecture of TU-Delft). The two full-time PhD Students will be recruited for four years each, the standard time for a PhD in the Netherlands. Their scientific contribution to the work packages has been established on this basis, accounting also for the training time and writing demands of a PhD. The first PhD student (PhD1) will be recruited at the start of the project, from a field of spatial science (geography, sociology, planning or economics for instance) and with demonstrated skills in statistical analysis. The second PhD student (PhD2) will be recruited a few months into the project, from the field of computational social science and with demonstrated skills in agent-based modelling. The postdoctoral researcher (PDR) will be recruited full-time for three years, during which they will contribute to the modelling work packages WP3 and WP4 and to the reproducibility package WP6. Their profile is that of a computer scientist or a computational social scientist with very strong technical skills.

B. Subcontracting costs = 67 000 euros

Some aspects of model exploration (WP4) will be subcontracted. In particular, the subcontractor will provide accompaniment, expertise and high-performance computing capabilities in the phases of sensitivity analysis, robustness analysis and model calibration. The costs have been estimated at 60 000 euros in total for about 200 hours of assistance throughout the project.

The required financial check will be performed by an external contractor. 7 000 euros are budgeted for it.

C. Purchase costs = 157 600 euros

C.1 Travel and subsistence = 43 600 euros
The presentation of the project results at international conferences and local seminars by the four members of staff is important both for the publicity of the project, for gathering expert feedback, and for the advancement of early career researchers. The budget allocated to travel & accommodation and fees per conference (estimated on average at 1 000 and 400 euros respectively) should allow the PI and the postdoctoral researcher to each attend two major international conferences per year, and the PhD students to attend one major international conference per year for the duration of their contract. Additionally, each project member will be allocated an extra budget of 2 500 euros in total to spend on visiting European institutions to discuss their work with teams specialised in urban economic segregation, agent-based modelling and public policies, during seminars or more informal research meetings. The total budget for travel and subsistence thus consists of 1 400 x 2 x 5 + 2 500 = 16 500 for the PI, 1 400 x 2 x 3 + 2 500 = 10 900 for the PDR and 1 400 x 1 x 4 + 2 500 = 8 100 euros for each PhD Student.

I have also budgeted 2 000 euros for the rental of server space to store the large amount of data generated by simulations during these analyses.

C.3 Other goods and services = 114 000 euros

This includes in the first place the costs of scientific related training courses. Some are provided for free by the graduate school or their costs is covered by the university for its staff members (this include Dutch language and leadership courses). Other courses will have to be purchased (up to 10 000 euros in total). Depending on the staff recruited and their skills, these might involve advanced trainings in big data analysis, in agent-based model programming, in high-

performance computing and in public policy evaluation, through university courses, summer schools or other institutions.

Additionally, three events are planned in the research proposal. The first event corresponds to a summer school on urban simulation during the third or fourth year of the project. This event is planned to disseminate both the results of the action and the innovative modelling methods and practice to the new generation of urban modellers. The 10 000 euros budgeted for this event should cover the cost of hosting a dozen participants, selected among PhD students and early career researchers. The second event corresponds to a two-day policy workshop on urban economic segregation, which is expected to test the applicability and reception of our research results on policy makers. The 10 000 euros budgeted for this event should cover the costs of hosting about twenty participants, mostly from the Netherlands. They will both take place in Delft and part of the costs will be supported as an in-kind contribution by TU Delft (provision of rooms, recording material, secretarial staff support, communication, etc.). In-kind contribution by TU Delft will not be claimed on the ERC budget. The third event corresponds to a coding camp, i.e. an event where the SEGUE project members and participants from other institutions would work intensively together on a programming problem or challenge. The 10 000 euros budgeted for this event should cover the costs of hosting about ten participants.

TU-Delft has agreements with many scientific journals to publish articles with open access, therefore we only need this budget to cover the costs of publishing the synthesis book in open access. 12 000 euros have been budgeted for this publication, which corresponds to the cost of publishing a book in open access with prestigious editors such as Routledge or Springer.

Finally, the empirical analysis planned in WP2 requires the PhD1 and the PI to access CBS microdata. This data will also be used within WP4 to calibrate the multimodel by the PhD2, the PDR and the PI. Microdata corresponds to individual information about the entire population of adults who reside in the Netherlands (14 million) within a secure remote environment. This unique data is made accessible by the public office for statistics CBS to accredited researchers. Access to this service involves fixed costs (creating a project, adding researchers, adding topics and datasets, uploading external datasets) and recurring costs (monthly access to datasets, monthly access cost per researcher, output control). I have estimated these access costs to 60 000 euros in total, to allow the entire team to work with a large array of datasets and variables for four years out of five (I exclude the starting phase and the synthesis phases at the start and end of the project, during which access to the data will not be required).