FORM-ACTIVITY-MOVEMENT INTERACTION MODEL

Study of the Interactions between Urban Form, Allocation of Activities and Pedestrian Movement in Weimar, Germany

Dissertation

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Theses

Background & Problem Statement

1. The effect of cities and their form on human activities and movement has wide-ranging social, economic, and environmental implications. Our understanding of the relationship between urban form, movement, and allocation of activities plays a central role in mitigating the negative and fostering the positive effects of urbanity.

2. Cities are complex systems, and thus the process of building and planning cities is a complex task. To address the complexity of cities, urban planning involves a multitude of disciplines with professionals coming from different fields (e.g., urban sociology, transportation planning, landscape architecture) with a different methodological background (e.g., qualitative vs. quantitative methods, induction vs. deduction) and different focus or priorities.

3. When it comes to understanding the interaction between the urban form and movement and allocation of activities, we find urban economists (UE), configurational urban morphologists (CUM), and transportation planners (TP) proposing each their own explanation. Each discipline focuses on specific parts of the form – activity - movement (F-A-M) interaction while ignoring others. As a result, we see the same variables being considered by some experts as dependent, by others as independent, or being dismissed altogether.

4. Even though there is no doubt about the advantages of simplicity of the individual approaches proposed by TP, UE and CUM, it remains unknown how they combine and what is the cost of ignoring some interactions between F-A-M. Consequently, the goal of this study is to empirically test the validity of the individual approaches used to assess the effect of urban form on movement and allocation of activities.

State of Research

5. Different models explaining the interaction between urban form, movement, and allocation of activities have in common that they all are an imperfect simplification of reality, and in a strictly formal sense, they all are wrong. Thus, there is no such thing as a true model, but only models that are useful.

6. The usefulness of the model is characterized in terms of its accuracy, consistency, efficiency, and bias. From these model characteristics, the bias is of central importance as it suggests not only imperfection but a systematic error in a model that renders it misleading.

7. The essential elements of urban form are the street network, the plot structure, and the buildings. Once established, these elements have a long-lasting impact, with the street network being the most stable constituent of urban form.

8. The Street network and buildings are of special importance when it comes to facilitating movement and allocating human activities. They create a physical barrier that guides the movement and present a shelter that host activities.

9. The social, economic, and environmental effect of movement depends on the mode of transport. Motorized travel has been related to a wide range of negative externalities (e.g., air pollution, greenhouse emissions, social exclusion). On the contrary, the pedestrian movement has been proven to be an almost universal solution to multiple issues ranging from individual health, crime, social segregation to environmental problems. Nevertheless, it is only little known about the effect of urban form and allocation of activities on pedestrian movement as most models traditionally focus on motorized travel.

10. The notion of activity is based on the concept by which the purpose of the movement is not to reach a destination but rather to fulfill the individual needs (e.g., hunger) by performing a particular activity (e.g., visiting a restaurant). The concept of activities is closely related to the concept of land use, it is however more useful when the goal is to explain the movement.

11. Transportation planners (TP) explain pedestrian movement as derived demand. It is understood as an external product of the aim to reaching a particular activity. As a result, the movement is a product of allocation of activities with urban form playing only a role of the interface.

12. Urban economists (UE) focus on explaining the allocation of activities as a function of their spatial interactions. They pay only a little attention to spatial representation, depicting the urban form as a featureless Euclidian plain.

13. The configurational urban morphologists (CUM) explain both, the movement and the allocation of activities as a pure product of urban form. They assume activities to be equally distributed or follow the potential given by the urban form. As result the allocation of activities is ignored in the CUM model of movement.

14. The approaches of UE and TP focus on the interaction between movement and activities and do not allow to quantify the direct effect of urban form. Therefore, both approaches are of little use in early planning stages when decisions on the urban form are made, and the information on movement and allocation of activities is not available.

15. The approach of CUM is capable of informing the early planning stages about the long-term effects of urban form on the allocation of activities and movement. Nevertheless, it is unclear how ignoring the allocation of activities affects the accuracy and bias of the CUM model.

16. The CUM approach and the TP approach stand in apparent contradiction to each other as TP claim that movement cannot be modeled without the information on activities, while CUM routinely accomplishes this by modeling movement as a pure function of the urban form.

Methods

17. The contradiction between CUM and TP is resolved by splitting the overall activity and movement patterns into their exogenous and endogenous components. Endogenous components are part of the feedback loop between movement and activities. The exogenous components are the product of urban form only.

18. With movement and activity patterns separated by their exogenous and endogenous components, all interactions suggested by the CUM, TP, and UE approach are combined into a joined F-A-M interaction model. It simultaneously accounts for the direct impact of a) urban form on activities and movement, b) the mutual interaction between movement and activities, and c) spatial interaction between activities themselves.

19. Testing the validity (i.e., bias) of the CUM approach is based on empirically study comparing the estimates of the CUM model to the outcome of a joined F-A-M interaction model.

20. The empirical test accounts for the effect of activity type (i.e., different activities might be affected differently by pedestrian movement and urban form). The following six most relevant travel activities in the study area of Weimar have been considered: administrative, educational, gastronomy, healthcare, shopping, and work activity.

21. The empirical test of the CUM validity and the calibration of the joined F-A-M model has been conducted on the case study of Weimar, Germany. The empirical data capture a) the urban form (street network and distribution of buildings), b) the pedestrian movement flows, c) route choice behavior, d) travel diaries, and e) the distribution of travel activities.

22. The exogenous and endogenous model components and their relationships cannot be empirically measured and must be estimated from the empirical data on the overall distribution of movement and activities.

23. Calibrating the movement estimation model parameters requires determining the distance decay function and the route choice method. The pedestrian willingness to walk in Weimar is marginally below the national average and significantly above the well-established control study conducted in the North American context. The best performing route choice model in the study area is based on the cognitive shortest paths. This suggests that pedestrians in Weimar tend to choose the path which is easiest to navigate even if it is not metrically shortest.

24. To address the spatial autocorrelation and non-normal right-skewed bi-modal distribution of the activity allocation, we developed a novel Filter-Amplifier statistical model. It is used to quantify the effect of urban form and pedestrian movement on the allocation of activities.

25. To estimate the effect of urban form on movement, we formulated a penalized regression model. It guarantees that only non-negative movement estimates are allowed. This is necessary as the traditional linear regression model allows for conceptually implausible results (i.e., negative movement flow).

Findings

(*All statements are limited to the case study of Weimar*)

26. The urban form and allocation of activities are significant predictors of pedestrian movement.

27. The majority of pedestrian trips has been identified as a product of the allocation of activities. The direct contribution of urban form alone accounts for minority of the pedestrian trips.

28. If the direct effect of urban form is estimated in isolations (i.e., without considering the allocation of activities) as it is common practice in CUM, the estimate is systematically upward biased.

29. The pedestrian movement passing through a given location is a significant predictor of the presence of all six considered activity types.

30. Pedestrian movement explains a significant portion of the variation in the intensity of gastronomy, shopping, and work activities. In the case of these activity types, the pedestrian movement was able to predict not only if they are present but also at which intensity.

31. Estimating the effect of exogenous pedestrian movement (i.e., generated by urban form) on the allocation of activities in isolation (i.e., ignoring the effect of pedestrian movement generated by activities themselves) leads to bias.

32. Gastronomy and work activities are spatially autocorrelated. The strong negative autocorrelation of gastronomy means that the increase in intensity of gastronomy activity at a given street reduces the gastronomy intensity at the neighboring streets. In the case of the work activity, the opposite relationship has been found.

Relevance & Outlook

33. The joined F-A-M interaction model is reveals the gap between the actual and the potential activity intensity at various locations. By quantifying the potential gap, we can assess the neighborhood's unutilized capacity to accommodate activities, explore its causes, and devise actions to alleviate it.

34. The need to simultaneously consider the effect of activities, movement, and urban form implies that conventional analytical prediction models adopted by CUM, TP, and UE are biased and shall be used with caution when only information on the urban form is available.

35. The need to consider all F-A-M interactions simultaneously in order to prevent bias present significant difficulty for urban planning since the allocation of activities might be unknown at its early stages. We argue that in such a case, alternative approaches based on numerical simulation might offer a promising alternative.

36. The analytical model based on existing urban environments can be used to estimate the parameters of the simulation model (e.g., who is interacting with whom and how). The simulation model can be, in turn, used for future predictions. The prototype of such a form-activities-movement simulation model developed by authors demonstrates the feasibility of the approach as well as its challenges. Besides the computational complexity of the simulation, the main challenge is the absence of empirical data, which could be used to set the model parameters. This study provides the first sample of such interaction parameters, which still needs to be extended and confirmed by future studies.

Abstract

This dissertation investigates the interactions between urban form, allocation of activities, and pedestrian movement in the context of urban planning. The ability to assess the long-term impact of urban planning decisions on what people do and how they get there is of central importance, with various disciplines addressing this topic. This study focuses on approaches proposed by urban morphologists, urban economists, and transportation planners, each aiming the attention at a different part of the form-activity-movement interaction. Even though there is no doubt about the advantages of these highly focused approaches, it remains unclear what is the cost of ignoring the effect of some interactions while considering others. The general aim of this dissertation is to empirically test the validity of the individual models and quantify the impact of this isolationist approach on their precision and bias.

For this purpose, we propose a joined form-activity-movement interaction model and conduct an empirical study in Weimar, Germany. We estimate how the urban form and activities affect movement as well as how movement and urban form affect activities. By estimating these effects in isolation and simultaneously, we assess the bias of the individual models.

The empirical study is accompanied by a series of analyses aimed to calibrate the parameters of the form-activity-movement interaction model. We examined the effect of route choice model, travel impedance, and daytime on pedestrian movement. Additionally, we introduced the concept of movement as multi-dimensional phenomena, described by four distinct movement characteristics. We discuss their theoretical properties and their distribution pattern across the study area. In the course of the model calibration, we identified two distinct processes driving the allocation of activities and devised a novel two-stage statistical model for estimating the effect of movement of their intensity. When it comes to estimating the effect of urban form and activities on movement, we formulate a special version of a linear regression which guarantees that only positive movement estimates are allowed.

On the one hand, the empirical study results confirm the significance of all interactions suggested by the individual models. On the other hand, we were able to show that when these interactions are estimated in isolation, the resulting predictions are biased. To conclude, we do not question the knowledge brought by transportation planners, urban morphologists, and urban economists. However, we argue that it might be of little use on its own.

We see the relevance of this study as being twofold. On the one hand, we proposed a novel methodological framework for the simultaneous estimation of the form-activity-movement interactions. On the other hand, we provide empirical evidence about the strengths and limitations of current approaches.