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Generating Reality with Geosimulation Models: An Agent-Based Social-Spatial Network Modelling Perspective

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Abstract

Models in general and geosimulation in particular are epistemologically characterized by two principles: first, they produce reality through their existence and communication rather than simply representing it. Second, they reduce complexity in the process of mapping complexity. Since almost any current phenomenon is understood as complex without specifying how complex it is and in which sense, geosimulation models are important tools in solving this problem of specifying and representing complexity. This capability rests, among other things, upon its multilevel approach (bottom-up and top-down) and its ability to translate terms into numbers and thus into distinct singularities. A demonstration of such an understanding of models will be given by presenting a socio-spatial simulation approach in the domain of network analysis and social capital operationalization. Two Austrian regions serve as case studies using empirical and simulated data. The demonstration includes the endeavor to intertwine a place-based geography with a network-based geography.

Keywords: generative power of models, translating social capital into quantities, network mechanisms, semi-empirical model, network-based and place-based geography

1. Introduction

The mutual referencing of statements is a presupposition to comprehend the stated facts in a communication situation. Be it theories or methods, descriptions or explanations, texts or maps—relationships always create, explicitly or implicitly, these nexuses with which particularities are

being contextualized. Contextualization generates meaning. However, neither the creation of relationships nor the creation of meaning is grounded in objective and independent criteria, neither in science nor in everyday life. They are, on the other hand, not completely arbitrary, but depend on particular social-cultural, temporal (historical) and spatial (geographical) contexts.

The referential contexts emphasize in addition how, why, and that complementarities are fundamental for comprehensive reasoning. Complementarities can be dialectic; the decisive point is that they simultaneously express a mutually excluding *and* complementing relationship, as is the case of the dualism between wave and particle or of impulse and location in physics. One characteristic of complementarity is that the so far unconnected (or differently connected) components do already exist. Every social construction of space, for instance, presupposes spatial rules, patterns, and conventions which are independent properties compared with the social rules, patterns, and conventions being applied when taking possession of social space. Among others, spatial rules ground in geometry, topology, or algorithmic computation. This is equally true for every statistical analysis. The result of a model run or a statistical analysis presumes the selected technique which itself is based on concrete procedural rules (e.g., that interactions among agents and between agents and their environment are taken into consideration). The process of computing a number is usually not reflected in the result, except it is made explicit. In this respect, a mathematical emergence of reality does not differ from a textual or (carto-) graphical emergence of reality and in all cases we refer to *a priori* objectives, reflections, and so on. What makes a difference is the nature of translation.

For modelling geographical phenomena from a social scientific perspective, an understanding of relations and complementarities is crucial because both spatial and social facts do rely heavily on their inner-temporal dynamics and develop in time differently [1]. Social-spatial network processes and mechanisms may obey common rules of homophily or of addressing roles and positions. The quality of the processes and mechanisms, however, together with its concrete manifestations of allocations of social, cultural, economic, and spatial capital is influenced by the idiosyncratic peculiarity of their local, temporal, and community compositions.

With these introductory remarks, we aim to highlight the underlying principles in the creation of meaning and intentionality derived from abstract information [2] and dedicated to be used in scientific, political and everyday-life communications. The notion of communication is used here as a means of providing us with the capability to deal with our perceived and interpreted environment in a meaningful way. This aim implies a closer look into the functions and purposes of models and quantifications, and is tied to the challenges that arise due to the referencing of complementarities, of numbers and words, of quantifications and qualifications.

2. The nature of models and quantifications and their impacts

2.1. The peculiarity of quantities and quantifications

In contrast to the common understanding of quantities which are assumed to devalue the individual as an abstract number and negate its qualities, it is Lewin ([3], p. 150) who appreciates

the peculiarity of quantification: "It is the increased desire, and also the increased ability, to comprehend *concrete particular cases*, and to comprehend them fully, which, together with the idea of the *homogeneity* of the physical world and that of the *continuity* of the properties of its objects, constituted the main impulse to the increasing quantification of physics." Numbers, quantifications and their emergence through quantitative methods are one possibility for raising a kind of uniqueness to facts, phenomena, and events which cannot be realized by the other approaches. "There is nothing more abstract and singular than numbers. Beyond numbers no further abstraction is thinkable, because abstracting from numbers would mean to disregard singularity. This in turn would mean to give up the Self, because the Self is only possible in contradiction to 'Another'" ([4], p. 4; translation A.K). It is worth noting that contemporary sociological and philosophical approaches to modern societies increasingly take the concept of singularity into account. [5–6]. Weiss [4] also points out that quantity (the single part) and quality (the whole) conflate; they can be distinguished analytically, but need to be mutually related in order to understand both sides of the coin—and the coin.

The complementarity of quantity and quality, of quantification and qualification, is realized through translation, and this procedure must be recalled when statements and numbers as well as their manifold representations are captured and utilized. Detractors of quantification tend to create an asymmetry between the two worlds. They argue that if a qualitative phenomenon is being tied to a number it will lose its eigenvalue—the only thing that counts henceforth is its numerical value. The processes and mechanisms of its creation, their cultural, geographical or temporal differences maintain obscured [7]. Though this problem definitely exists, it is not a problem of the quantification itself but a problem of exposing the cultural, political, social and scientific circumstances of its creation. Therefore, the use of numbers and words incorporates presuppositions about what is perceived as relevant and valuable.

2.2. Challenges of transformability of methods, numbers, and models

Measurements, quantifications and models result in one or many but always concrete single cases, as has been stated above. What they bear must be contextualized. From an epistemological perspective, it is the well-known threefold "context of discovery," "context of justification," and "context of utilization." Contextualization, in addition, must refer to other measurements and models in order to verify and validate model results, but also to utilize them comparatively in connection with other approaches [8]. What follows is not a competition between outcomes and paradigmatic settings but an abductive approaching to the explicit problem(s) at hand.

This may sound trivial. Indeed, the claim for *trans*formability of methodological approaches, of modelling aims and types among and between modelling paradigms, scientific and epistemological explanations has been uttered many times over the past six or so decades. One such utterance, apart from that of Thomas Kuhn [9], was made by Ludwik Fleck, a Polish physician who refused to accept an "absolute truth" as an epistemological counterpart of scientific exploration. He insisted on three social factors which inherently determine scientific reasoning ([1], p. xxii):

1. The "weigh of education": knowledge foremost consists of learnt items, being, however, then subtly transformed by learning and communication.

2. The "burden of tradition": new recognition is primarily coined by already existing recognition.

3. The "effect of the recognition sequence": what has been once conceptualized theoretically and/or methodologically restricts the opportunities of new concepts.

Incorporating these social factors into the evaluation of research results may help to relax the researcher from unobtainable truths and to focus more strictly on the processes and purposes of model production.

2.3. Utilization of knowledge, numbers and models

Taking the challenges of contextualization, translation and transformation explicitly into account would also mean having to deal with knowledge and models in a different way. The qualitative experience with social phenomena and problems feeds mainly on very subjective and local living conditions; it is, however, simultaneously an amalgamation of aggregated knowledge as "socialized subjectivity" [10]. This kind of knowledge which refers to local and subjective-social living conditions can be termed "local knowledge." Local knowledge, though derived from a different epistemology and perspective (ethnography and natives in developing countries) [11], can be transferred to contemporary (post)modern, globalized *and* localized living conditions as well. Local knowledge of people having, for example, a different social or economic status, living in impoverished or wealthy regions is, apart from scaling, important for social-spatial network analysis because it incorporates another mode of observation and perception. While knowledge about socioeconomic inequality or disparate living conditions in scientific and political contexts is mostly a perspective of people who are not affected by these disparities (a second order observation), local knowledge of socially discriminated and excluded people offers a first order observation.

In addition to mutual relationships between different modes of recognition, ordering, and understanding, it is important to account for the relationships within the quantitative methodology. It can be confirmed that "calculating is existing equality of opportunity" ([12], p. 43) because societal problems such as discrimination and inequality can be—and must be—made comparable through exact differentiation and objectivation which can then be used for opinion-forming in the political arena. As long as statistical analyses are considered as an instrument among others, one would be able to agree with the above quote. If not, the "equality of opportunity" turns out to be misused as ideology, representing an interest- and power-driven inequality of opportunity, since there is no longer explicit advice for a reduction of complexity.

A reduction of complexity is another and inevitable step in perceiving and grasping our world. It is, however, simultaneously necessary to deal with this reduction of complexity in an explicit and deliberate way. Explicit means to not only publish the results of an analysis but also the process of its realization. Deliberate means taking a critical attitude with regard to the chosen method(s) (see, among others, [13] for a detailed description of the creation of the "risk of poverty threshold" and its implications, and [14] with delineation of measuring poverty in London in the nineteenth and twentieth century).

Another problem of the internal confirmatory referencing of quantitative methods is the danger of not only making the measured values absolute but also the models and techniques applied. This problem can be phrased as "to explain the real through the impossible." Economics can serve as an example here: "Economics creates mathematical models which could never be built in reality but are used nevertheless to compute and reduce complex economic processes to a few numbers. Here too, they try to describe the real through the impossible. […] Neoclassical economics assumes a kind of market harmony. If markets are left to their own resources then everything develops well. Dummy arguments are used to confirm this opinion by misusing mathematics in order to circulate ideology" ([15], p. 112f, translation A.K). The critical point is not that quantitative methods deal with artificial experimental settings or models, but that they immediately equate models with reality. Instead, models— through their construction and focus—*create a reality* through their use in science and everyday life, which will be explained in more detail in the next section. In addition, the methodological and technological progress must also be thought of explicitly.

2.4. The purpose and meaning of models

For an appropriate appreciation of quantification and modelling, a different kind of concluding translation between method and epistemology seems to be necessary. Statistics often assumes an absence of ideologies and normative values which is not true when considering the modes of acquiring, producing, and publishing data and results, respectively. The basic instruments with which we observe, describe, explain, and interpret the world are models— there is no immediate access to our spatial and social environment.

This must be briefly explained. I agree with Schurz ([16], p. 56) who argues for a hypothetical-constructivist realism approach. According to this realism, our perception and imagination of reality is not *a priori* given, but constructed and conditioned through active cognition (which is referred to as "epistemic" constructivism). Contrary to an ontological constructivism which conclusively claims that reality too is not *a priori* given, the hypothetical-constructivist realism does not link perception and reality so tightly. Instead, it assumes a structural correspondence which transforms information between perception and reality, which is neither complete nor unambiguous. Taking such a corresponding linkage into consideration, it leads to an understanding of models that does not claim a straightforward coincidence of models with *the* reality, *the* nature, or *the* world. Models are not simply simplified representations of reality; they are images (imaginations) which we make from our environment. We constantly construct and reconstruct our environmental entry by using many and different instruments and tools proactively and interactively. These instruments and tools in turn influence our ways of (re-) construction. This making of is not always an act of creation, we also (and maybe mainly) use images (imaginations) made by others, be it maps, news articles, social network blogs, novels, theater plays, and the like. The application of images differs with respect to experience, social roles and positions, and many more contexts.

If this assumption of how reality can be accessed is true, then the role and meaning of models changes significantly. Models, then, are created, developed, and applied to generate reality, not to represent it (although representation remains one, but only one important characteristic).

In so doing, they untie from an assumed objective, true or total reality which has to be imitated by applying certain sets of rules. They establish a kind of independence. Models, moreover, reduce complexity in order to make the subject matter concrete. Hence, it is not the unimaginable, opaque complexity addressed theoretically to "reality" which is under investigation in models and computationally translated to quantities. Complexity of reality is a metaphor which will act as a counterpart to models, theories and quantifications. To compare it with system theory, we can conceive of characteristics of systems because they emerge as distinct objects structurally and functionally. Initially, we are not able to talk about a system's environment—it is just the unassigned other side of the system.

If the function of a model is not to represent or imitate the complexity of an unknown reality, then a model inhabits inherently its own justification by explicitly expressing its purpose, assumptions, and ways of reducing complexity. This is quite similar to map-making by applying rules of generalization or to statistical analysis by deliberately selecting variables and techniques in order to achieve a certain result.

The aim of this line of thought is to avoid absolute external reality as a reference in modelling, but instead putting the inherent purposes, assumptions, framing conditions, parameter settings, and so on in the foreground. In so doing, it is a realization of a modelling epistemology that has been claimed by several researchers, among others Epstein [17], by arguing for a "generative social science" which accounts for letting the phenomenon of interest grow in a simulation model of interacting agents, or Küppers et al. [18] who equate simulation models epistemologically with a "pragmatic construction of reality," whereby reality emerges inside the models (further hints are given in [19]).

It would therefore be more appropriate to refer to "originals" instead of "reality" which are being generated and represented by models. Originals refer to other originals and in doing so there is no need to refer to an absolute truth/reality. This is in line with Stachowiak's [20] General Model Theory, whereby models are defined through three characteristics: (1) a model is always a representation of a natural or artificial original, and the original can itself be an original; (2) a model does not encompass all attributes of an original, but only those which seem to be relevant for the model purpose; (3) a model does not conflate with the original inherently, but depends on the purpose, thus on the questions 'whereto,' 'for what and whom,' 'when,' and 'where.'

2.5. The risk of instrumentalizing models

Without relationships and associations, models and numbers tend to be used as ideology or sheer instruments. They become stylized facts, and the images (imaginations) they produce induce a kind of a factual inevitability. A social capital value derived from network analysis, a poverty threshold, or a correlation between voter turnout and social status is equated with reality that not even one of the parameters would represent as a single case accidentally. A related problem is given with the use of the notion of "optimization"—model optimization is often equalized with empirical optimization, misappropriating the purpose(s) and premise(s) of the model.

Complementary to the ideologization *of* models, we have to take the ideologization *through* models into account. Members of a social community or milieu potentially identify with scientific and political model results or analyses, be it confirmatory or deprecatory or something

in between. Mechanisms of self- and external exclusion are one of the most negative and sustainable effects of stigmatized identification.

3. Social capital as a reference in social-spatial network modelling

The facts and problems that have been addressed so far, in order to adequately deal with models in general and geosimulation models in particular, will now be put into the context of social-spatial network modelling. The contextualization of information and the mutual transformation of complementary reference units in social network analyses are, *inter alia*, challenged by the difficulty of translating terms into numbers—in other words, of quantifying notions of social capital, solidarity or trust. Before introducing a geosimulation network modelling approach that attempts to explicitly struggle with this difficulty methodologically we begin with a brief delineation of the theoretical problem.

"Social interactions in collective human relations are commonly understood as a fundamental condition for human beings to live a satisfactory life. Establishing a personal identity and autonomy on the one hand, and trust, solidarity and commitment on the other hand require social-normative rules which function as a glue that helps agents to connect to one another. While the nature of social interaction is seen as an unquestioned fact its valuation in operational terms is much harder to achieve. One apparently and generally accepted approach to operationalize the value of social interactions is given by the theory of social capital. A huge body of theoretical reflections as well as empirical studies [21, 22] consider transferring the concept of economic capital into the social realm as a suitable methodology for coping with social relations" [23].

"The size and composition of social networks rely to a large part on the characteristics of the actors involved, i.e. their capabilities, needs and aspirations to collaborate with others. They also depend on the reasons for cooperation, the kinds of problems, and the (in)tangible infrastructure necessary to communicate via different channels. An important additional issue, however, comes with the nature of network mechanisms themselves – the process of how relations between actors emerge structurally and which determinants are thought to be relevant" [23]. There are several different approaches which relate the analysis of network mechanisms to social facts, one of which is dedicated to social capital.

Bourdieu ([24], p. 248) defines social capital as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition." This definition is in favor of an actor-centered and utilitarian perspective that not only presupposes an affiliation to one or many social networks as a constituent characteristic, but also assumes knowledge about the structure and function(s) of these. Networks vary significantly in size and complexity; they can be concrete and manageable as, for instance, families and cliques as well as abstract and opaque, as is the case for associations, organizations, labor markets, or electoral rolls. [25]

Furthermore, it is remarkable that the unit of value, the currency, is implicitly given by solidarity, reciprocity, and trust, expressed explicitly as network connections, however. "The volume of the social capital possessed by a given agent thus depends on the size of the network of

connections he can effectively mobilize and on the volume of the capital (economic, cultural or symbolic) possessed in his own right by each of those to whom he is connected" [25]. This quantitative relation—the more connections one has the higher his/her social capital is—sounds odd because it makes no qualitative difference in terms of network structure (density of relations) or the nature and value of relations (positions and roles of agents, weights of directions). "Resources" within the social capital context are understood as the availability of network relationships, which are, however, not specified—neither quantitatively nor qualitatively. A functional approach to social capital differs from an actor-centered one and accounts more suitably for assigning value to social relation: "Social capital is defined by its function. It is not a single entity, but a variety of different entities having two characteristics in common: They all consist of some aspect of a social structure, and they facilitate certain actions of individuals who are within the structure" ([26], p. 302).

An understanding of social capital is commonly embedded into a broader conceptualization of capitalizing social relations. While this idea is tempting with economic capital, it is less so with social capital. "The three functions of capital and money, respectively, are (i) a means of exchange, (ii) a means of value hedge and preservation, and (iii) a unit of calculation." Accumulation may play a major role in all of these functions, but is not restricted to them. The worth of capital also stretches to the functions of distribution and circulation within a commodity and service economy [27]. Taxation and social security contributions are other examples of how capital is used. In addition, economic capital accumulation implies accumulation of both surplus and debt. The execution of all these functions requires not only a general usability of capital but also a (statistical) scale of measurement that enables comparisons and evaluations across a diverse field of objectives, and of spatial and temporal scales. All this is not given—or not sufficiently so—with social capital. It is possible to weigh and to qualify the direction of network relations, but still no adequate measures are available which account for the latent variables associated with social capital. In other words, it makes no sense to say "we must double solidarity or trust by doing X." It would, however, be a scientifically fruitful endeavor to develop indexes of social capital—based on trust, solidarity, network relations, etc.—with the aim of investigating social networks comparatively." [25]

In so doing, a strategy of obscuring or fuzziness is not constructive as can sometimes be detected in qualitative empirical social network research. For example, Dill ([28], p. 85) claims for his own approach that a definition should be a clear and simple one: "Social capital is the sum of intangible merits and goods within a community" (translation A.K.). In fact, this definition is anything but clear and simple. What can be accepted as "intangible merits" in communities and by whom? Who or what defines communities, and why are we dealing now with communities instead of networks? Are they identical? Who is producing and who is consuming intangible goods, based on which distribution rules? How does one sum up intangible goods? This definition is different from the accumulation and the "unit of calculation" concept because it provides no clues about distributional rules (it is a simple sum), the nature of intangible goods, and the nature of communities (which is much harder to specify than talking about social networks). The distinctive property of social capital in comparison with human or economic capital is, according to Dill [28], totally idealistic nature.

The following chapter presents one attempt to operationalize the qualities that are associated with social capital in quantitative terms in the context of a social-spatial network. It seeks to address the problem of team assembly mechanisms (the topological space) with its potential impacts on the spatial distribution of these teams (the chorological space) in terms of the success experienced in conducting their projects.

4. An agent-based geosimulation model of a semi-empirical social network

4.1. Introductory remarks

The basic idea of the approach to translate the qualitative characteristics of social capital into quantitative properties is given with the number of face-to-face meeting opportunities. Though we are aware of the fact that the creation and continuation of social relations today are significantly influenced, or even determined, by social media technologies occupying virtual spaces, we are convinced that meeting opportunities of physically present people also have a strong impact on the process of tying relationships between them. The purpose of investigating networking mechanisms is, therefore, threefold: first, the geosimulation model simulates processes that represent the evolution of a large(r) network derived from a finite number of small(er) team networks. This evolution is thought to represent an increase of network connections, that is, an increase of social capital. Second, the model seeks to carve out the statistical meaning of our core variable *number of face-to-face meeting opportunities* as a latent variable that points to one condition of creating and allocating social capital. Third, since face-to-face communication takes place in physical space, the geosimulation model is used to analyze potential theoretical relationships between a network-based and a place-based geography.

With respect to our interest of studying networking mechanisms, we argue that the evolution toward a large connected network contributes to overcoming isolated and fragmented efforts toward a common goal. Achieving synergies through effective trans-local knowledge transfer is a goal that has been investigated in (social) network analysis for some time [29–31]. In this respect, agent-based simulation is an appropriate method to explore the underlying processes that lead to these networking mechanisms [32].

As a first step of this investigation, we selected and then adapted to our own needs a theoretical reference model developed by Guimera et al. [33] and made available as a NetLogo model by Bakshy and Wilensky [34]. The question raised ([33], p. 699) remains evident to some degree in our context too: "Is there a large connected cluster comprising most of the agents or is the network composed of numerous smaller clusters?" The ideal size does not necessarily correspond simply to exactly one all-encompassing network: "Successful teams evolve toward a size that is large enough to enable specialization and effective division of labor among teammates but small enough to avoid overwhelming costs of group coordination" ([33], p. 697). Where our empirical research is concerned, we are less interested in economic costs than in the creation of sustainable social interactions.

These assumptions are taken as relevant premises for networking mechanisms. In so doing, our focus shifts to the parameters that influence or determine the construction of large(r) social networks that are initially small and more or less isolated due to the design of the social project. These mechanisms are understood as operators of translating social capital into quantitative units. The parameters used can be divided into three general domains: (i) actor-based parameters, (ii) linkage-based parameters and (iii) place-based parameters.

4.2. The empirical case studies

The empirical case studies for which an agent-based simulation model was constructed, one which relies theoretically on the prototype model, derives from an Austrian social project entitled "Keep the Ball Rolling." This project aims to enhance social well-being at a regional level by encouraging the local population to put into practice ideas that they are convinced are relevant. Individuals or small teams are called to submit project proposals that help reduce social injustice and promote social cohesion. Successful teams are awarded a grant to fund their projects, and in addition receive organizational support. The project started in the Lungau region (Salzburg) in 2011 and was taken up by Steirische Eisenstrasse (Styria), Mühlviertler Alm (Upper Austria), and Mostviertel Mitte (Lower Austria) regions [35–36]. The empirical data used for the following simulation models are from the Styrian and Upper Austrian regions.

The project proposals are presented by the teams at three jury meetings. The successful candidates must implement their projects within 18 months. Every jury session is followed by a public celebration where the successful projects are presented. Because the implementation of a project is supported scientifically by a team of researchers for the duration of the project, several further meetings, ranging from small informal meetings to larger stakeholder workshops, are offered. Every team leader is invited to participate in a semi-standardized questionnaire designed to obtain knowledge about the project team in terms of its size and composition.

The analysis is concerned with how the number of such meetings (1) determines the team assembly mechanisms, (2) correlates with other determinants and (3) correlates with a place-based geography.

4.3. The model design

In order to analyze the development of collaborative socio-spatial network structures of initially small(er) and unconnected teams in two Austrian regions, a simulation model was constructed that includes some of the general ideas of the original model [33]. However, there are a number of major differences between our model and the original one: (1) The number of teams is initialized at three time steps and not stepwise; with this adaptation, we represent the selection process of successful teams. (2) Teams can vary in size. (3) Teams can also vary in network structure, while the original model only allows the implementation of teams of three actors that are fully connected, the "Keep-The-Ball-Rolling" project does not have such restrictions. (4) Individual agents (and not only teams of three agents) are inserted as new potential collaborators; this feature will play a crucial role in the future modelling process when data sets are available that will be collected approximately 2 years after the official

end of the social project (data for the Mühlviertler Alm region are currently missing, while data for the Steirische Eisenstrasse are not yet fully edited). Therefore, we do not refer to this characteristic of the model in this paper. (5) The original teams can be merged, either by a team leader (i.e., the leader of a project team) or by a team member (which is not possible in the reference model) who is selected stochastically for a new connection. This adaptation was implemented due to the nature of events that are realized during the different types of project meetings which can consist of stakeholder workshops, project presentations and informal meetings, as well as *ad hoc* assistance from the staff of the regional offices. Although we do not consider these different event properties explicitly, they remain important to justify the "connecting role" of both agent types, that is, team leaders and team members. The original model takes only team leaders as connectors into account.

The construction of the two regional socio-spatial network models is based on standardized questionnaires that were conducted at the beginning of the project in each region. Every team leader of a project who was awarded a grant to participate with her/his project and who took part in the survey was asked about her/his team collaborators. We also know the team leader's home address (but not those of the collaborators, which affects the analysis). The numbers of actors and network ties are given in **Table 1**.

The two models are initialized with these settings of nodes and edges. In the style of the reference model, a six-dimensional parameter space is used to analyze the networking mechanisms among team leaders, team members and between them. The aim of this procedure is to detect common patterns of relevance of and relationship between the six parameters that seem to determine the behavior of social networks in terms of their structure and dynamic. **Table 2** gives an overview of the parameters and the ranges of values within which the further simulation results have been analyzed.

The parameter *selAgents* determines the likelihood that agents attending an event are willing to collaborate; for example, *selAgents* = 50% means that 50% of all attendees of a workshop are willing to collaborate. The parameter *selAgentType* specifies which agent type—the team leader or the team member—is more likely to be willing to collaborate. If *selAgentType* = 50%, both agent types are equally likely to be willing to collaborate; if *selAgentType* < 50%, more team leaders are likely to be willing to collaborate. The interval of both parameters has a large range in order to detect network differences because of asymmetric probabilities. The maximum number of agents who are likely to collaborate, *maxSelAgents*, is a conservative estimate based on our experience of events we have organized in both regions. These three parameters affect the behavior of the agents, while the following two affect the relationship

Number of ...	Team leaders	Team members	Network ties
Styrian region	79	396	441
Upper Austrian region	59	418	655

Table 1. Number of registered team leaders, team members, and network ties among and between them in the Steirische Eisenstrasse (Styrian region) and the Mühlviertler Alm (upper Austrian region).

between them. The *conTeamLeader* and *conTeamMember* parameters determine stochastically how agents connect among themselves. If, for example, *conTeamLeader* = 10%, then in 10% of all cases team leaders connect with other team leaders, and in 90% of all cases they connect with team members. The same rule applies to *conTeamMember*.

The last parameter of **Table 2**, *numEvents*, determines the number of events that take place during a simulation run. This is our core parameter for implementing social capital as a quantitative approximation. Events are defined here as face-to-face meetings and hence exclude Internet-based communications. The range of values varies between 1 event and 160 events. Taking into account that one simulation run takes 160 steps, which represents a time period of 160 weeks or almost 3 years (i.e., the project time of approx. 80 weeks and the post-project time of another 80 weeks when *a posteriori* questionnaires are conducted to evaluate the sustainability of the projects), the number of events varies between just one meeting during or after the social festival, and meetings on a weekly basis.

The social network simulation models were created using NetLogo 6.0 [37]. The analysis of the modelling results has two stages: first, a statistical analysis composed of a multivariate linear regression analysis and a cluster analysis was conducted. Second, a simulation analysis consisting of representative simulation runs investigated the behavior of the social networks by considering the network parameters 'closeness centrality' and 'betweenness centrality.' **Figure 1** represents the simulation process graphically. The model used here is available as an updated version at OpenABM (https://www.openabm.org/model/5583/version/1).

4.4. Some selected model results

All possible combinations of values (that is, 3888 in this case) within the intervals of the six variables were computed, which led to 3888 mean values across all variations. These mean values were then used to compute average bivariate correlations and measurements of

Parameter	Description	Interval of analysis
selAgents	Probability of selecting agents per event who are willing to collaborate	[20, (30)[1], 80] %
selAgentType	Probability of selecting team leaders or team members per event who are willing to collaborate	[20, (30), 80] %
maxSelAgents	Potential maximum number of agents per event who are willing to collaborate	[4, (4), 12] abs.
conTeamLeader	Probability of team leaders actually connecting with other agents	[5, (15), 35] %
conTeamMember	Probability of team members actually connecting with other agents	[0, (10), 30] %
numEvents	Number of events that enable the establishment of new ties over a complete simulation run	[1, 2, 4, 8, 16, 32, 40, 80, 160] abs.

[1]Values in round brackets indicate the increment value; for example, the parameter values for *selAgents* are 20, 50 and 80.

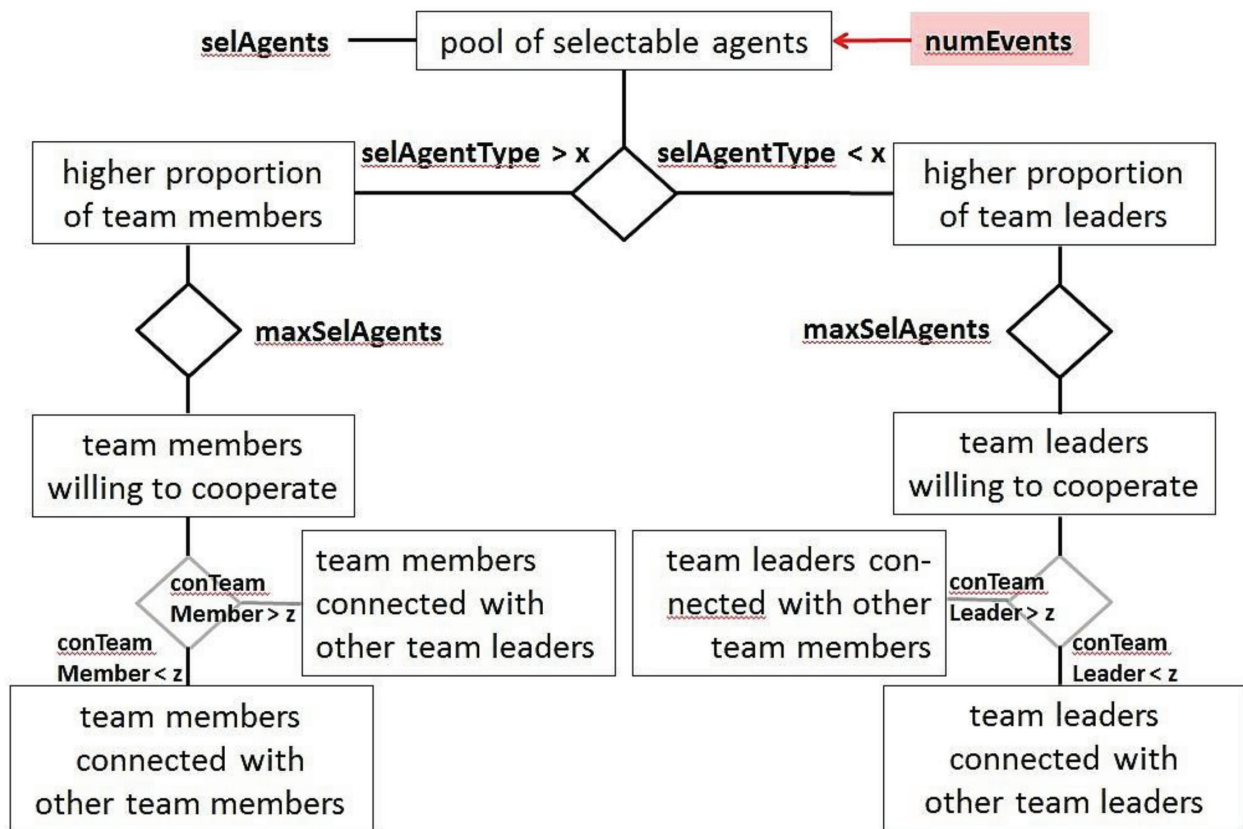**Table 2.** Description of parameters used in the simulation models.

Figure 1. Flow diagram of the simulation model.

determination. The aim was to determine the strength and direction of relationships of the six independent variables by which the versatile network structures can be explained. The emergence of these different network structures consists of both the initial network relations of the original teams (empirical data) and the network relations created during the simulation (modeled data).

The method used to create multiple regressions was "stepwise selection," which avoids multicollinearity to some degree. **Table 3** reveals that our core parameter *numEvents* is the most relevant independent variable for all three dependent variables representing the linkages between nodes. The measurement of determination (R^2) confirms this statement. The parameter *numEvents* is, however, more relevant to explain the variation of the distribution of the links among team leaders than among team members. On average, team leaders benefit more than team members from an increase in the number of workshops and meetings. This is due in part to an implicit bias, occurring because there are fewer team leaders than team members, which quickly leads to a higher number of linkages. This assessment is confirmed by the contrary fact of there being only a few events (1–8): under this condition, team leaders are far more involved than team members in creating a large connected social network. This fact has to be taken into account to avoid lock-in effects of a well-informed stakeholder group. The statistical influence of the remaining five parameters is significantly less relevant in explaining the variation of ties among and between the two groups when compared with *numEvents*, as is illustrated in the last column of **Table 3**.

Dependent variable	Most relevant independent variable	R² of most relevant independent variable	R² of all included independent variables
Number of connections among team leaders (Styria)	Number of events r = 0.785	0.617	0.759
Number of connections among team leaders (Upper Austria)	Number of events r = 0.779	0.606	0.751
Number of connections among team members (Styria)	Number of events r = 0.633	0.401	0.525
Number of connections among team members (Upper Austria)	Number of events r = 0.623	0.388	0.505
Number of connections among all actors (Styria)	Number of events r = 0.756	0.572	0.687
Number of connections among all actors (Upper Austria)	Number of events r = 0.735	0.540	0.652

Table 3. Regression patterns of the three dependent edge-related variables for the Steirische Eisenstrasse (Styria) and the Mühlviertler Alm (Upper Austria).

The cluster analysis aims to explore further structures that have been unknown so far. The cluster algorithm used here is the "Ward method," which yields more or less evenly distributed clusters. A variation of 4–6 clusters was applied, and the solution with five clusters provided good results with respect to a good discrimination of the values and interpretation of the results. As **Tables 4** and **5** illustrate for both regions in a very similar way, the highest numbers of connected agents (cluster 5 in both cases) are achieved when *numEvents* is the highest (which is not surprising), the likelihood of selected agents is relatively high, the proportion of team leaders is higher than that of team members, the maximum number of potentially selectable agents is relatively high, and the likelihood that agents will establish ties is high. If more team members are likely to be selected (*selAgentType* > 50%), then a considerable decrease of realized linkages follows. The least relevant parameters are *conTeamLeader* and *conTeamMember* (although they are responsible for the relevant discrimination between cluster 4 and cluster 5 in the upper Austrian case study).

Although *numEvents* appears to be a highly relevant determinant in the development of large network compositions, it is also highlighted in the cluster analysis results that team members benefit significantly from an increase in the number of events. A comparison of cluster 1 and cluster 2 for the Steirische Eisenstrasse reveals that almost doubling *numEvents* leads to a considerably higher increase of tied team members (approx. 2100 compared with 800) than of tied team leaders (approx. 1500 compared with 700).

In addition to the statistical analysis, a simulation analysis was performed in order to investigate the process of the network creation. For this purpose, two common centrality measures were used, namely the closeness centrality and the betweenness centrality. Both centrality measures characterize an agent's position or role in the entire network. In NetLogo, closeness

Dependent variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
number of ties among team leaders	700	1041	156	1263	1415
number of ties among team members	805	2075	83	3402	9074
number of all ties	2132	4248	497	7824	10,423
Independent variables					
numEvents	73	118	18	141	160
selAgents	58	58	47	70	73
selAgentType	52	50	51	40	32
maxSelAgents	7	7	6	8	8
conTeamLeader/conTeamMember	20/15	20/15	20/15	19/13	20/25

Table 4. Cluster analysis results for the Styrian case study. Values represent mean values.

Dependent variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Number of ties among team leaders	184	932	1004	1299	1364
Number of ties among team members	141	1458	5293	2682	10,459
Number of all ties	817	4056	7229	12,152	12,844
Independent variables					
numEvents	22	104	133	155	160
selAgents	47	60	66	70	72
selAgentType	51	51	38	34	34
maxSelAgents	6	7	7	9	9
conTeamLeader/conTeamMember	20/15	20/13	20/22	20/4	21/25

Table 5. Cluster analysis results for the upper Austrian case study. Values represent mean values.

centrality is defined as "[…] the inverse of the average of an [agent's] distances to all other [agents]" [38]. Distances are defined as shortest paths. Betweenness centrality, by contrast, refers to the mediator function of an agent (for example, mediating communication flows). To calculate the betweenness centrality of an agent, "[…] you take every other possible pairs of [agents] and, for each pair, you calculate the proportion of shortest paths between members of the pair that passes through the current [agent]. The betweenness centrality of an [agent] is the sum of these" [38].

Based on typical and representative simulation runs of the abovementioned behavior space analysis in NetLogo, a data subset with 32 cases has been extracted. Extraction here means that extreme values of parameters have been excluded; for example, *numEvents* was set to 80 in one case and to 8 in another. **Figure 2** illustrates the results of agents that have a high closeness centrality ("high" defined as above the threshold value of 0.5) for the Steirische Eisenstrasse region. The two maps differ in the number of events during the simulation run.
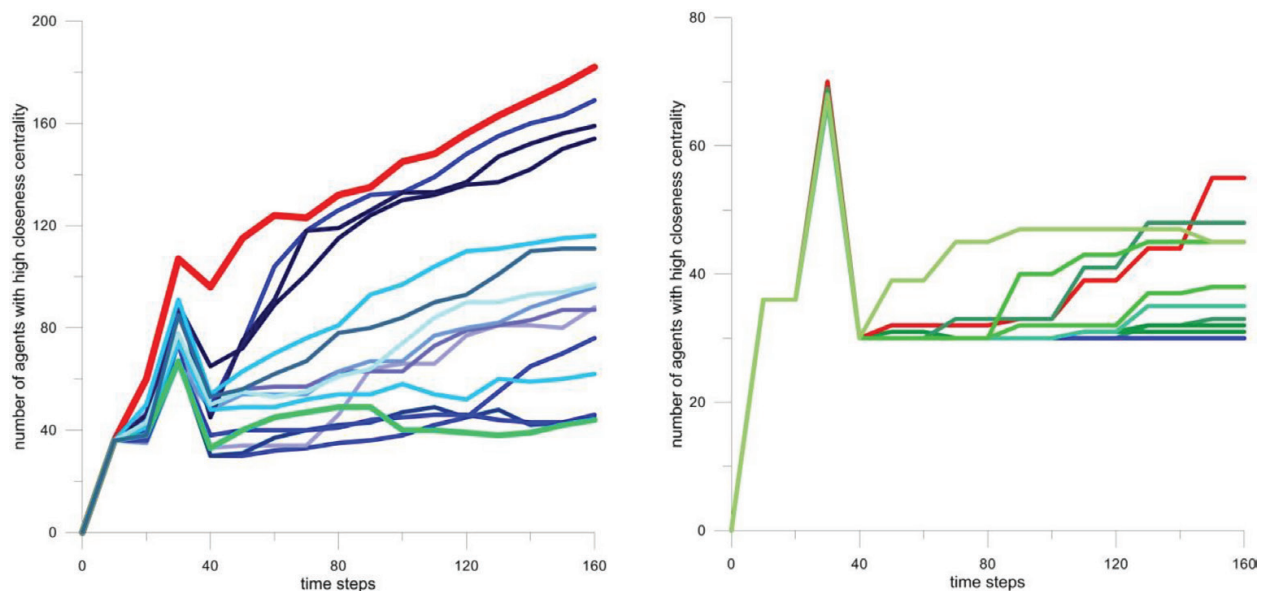
Figure 2. Distribution of high closeness centrality agents for *numEvents* = 80 (left) and *numEvents* = 8 (right) in the Styrian study area.

Sixteen out of the 32 simulation runs were executed using a high number of meeting events (left-hand side), while the other 16 used a low number of events (right-hand side). When we compare the two graphs of **Figure 2**, the most obvious fact is that the variation of results with *numEvents* = 80 is considerably larger than with *numEvents* = 8. The case representing the lowest number of agents gaining a high closeness centrality (green graph in the left diagram) is characterized by a high number of selected team leaders (because *selAgents* is high and *selAgentType* is significantly below the 50% threshold value) and by high linkage percentages for both agent types. The case with the highest number of agents gaining a high closeness centrality (red graph in the left diagram) differs in the relationship of *selAgents* and *selAgentType* which is now exactly the opposite. These results highlight the important contribution of team leaders in two ways: (1) they are important as central nodes within the social network; (2) they also act as multipliers for team members to achieve a central position in the network.

Fluctuations for cases with *numEvents = 8* (right diagram of **Figure 2**) are far less significant. Here, values range from 30 (blue graph) to 55 (red graph) (there are six different combinations of parameter values that lead to 30 agents gaining high closeness centrality). The most relevant determinants to explain the differences are *selAgents* and *conTeamMember* – one node-related and one linkage-related parameter. A comparison of the two diagrams of **Figure 2** convincingly shows that even a high number of events supplied do not guarantee a sufficiently high number of agents who are tightly linked together if the other parameter values do not foster successful collaboration efforts.

4.5. The geographical dimension of the social network geosimulation model

The statistical and simulation analyses reveal that the construction and (sustainable) consolidation of social networks are influenced by a high number of factors whose inter-relationships are quite complicated in terms of generating a large(r) connected network. Offering a high

number of events does not automatically ensure that a high proportion of agents will gain high centrality in order to provide for efficient knowledge transfer within the social network. In fact, even only a few events can result in a reliable number of durable linkages among agents.

However, one must take the specific sequence of the three jury meetings into account. Due to the inclusion of new team leaders and team members at predefined time steps, a temporary decline in the number of agents with high betweenness and/or closeness centrality can arise. Fluctuations are large(r) if the number of events provided is high because meetings are likely to take place between jury sessions, too.

Therefore, the organization of events to foster collaboration is a challenging undertaking, as social network analysis has shown. The supply of opportunities to meet each other in order to exchange knowledge and experience has, in addition to its qualitative component (obligatory stakeholder meeting vs. informal team meeting), a quantitative tendency. Setting aside all the network-based determinants discussed so far, one should not forget the geographical domain, that is, the geospatial distribution of the relevant actors. In other words, a translation from a space-of-flows geography to a space-of-places geography seems appropriate.

Figures 3 and **4** are representative extracts of the spatial distribution of agents with high betweenness centrality (yellow) and high closeness centrality (violet), and remaining team leaders (red) for a high and low numbers of events (*numEvents* = 80 and *numEvents* = 8 respectively). Linkages are hidden and the scale of resolution of the agents' locations, which is based on the questionnaire, is the municipal level. Distribution within the municipalities is for visualization purposes only.

One important conclusion that can be drawn from the distribution patterns is that the vertical structures of the social networks do not completely coincide with the structure of the places where the team leaders reside and where the projects were implemented. The initial network pattern is characterized by many small and largely unconnected teams each with one leader and a couple of members who are, of necessity, linked to the leader. This vertical structure was then reiterated as team leaders connected to one another or to other team members. Agents with high closeness and/or betweenness centrality are disproportionately more often located in municipalities with comparatively fewer implemented projects (light green colored areas). This is true both for situations with a high number of events and those with a low number. If a high number of meetings were to be offered (maps at the left-hand side), then the distribution of agents with high betweenness centrality (= important communicators) would be more even than the distribution of the projects. The result is true for the Styrian as well as the Upper Austrian study area. In fact, this statement can be extended to the situation of a low number of offered meetings if the closeness centrality (=strong ties between agents) is taken into consideration, as can be seen in the maps at the right-hand side of **Figures 3** and **4**. The peculiar relationship between the two geographies immediately prompts the conclusion that the decisions about adequate venues for meetings should be made by taking the whole project region into account and not concentrating mostly on the region's larger towns.

Another conclusion that can be drawn is that with a more even spatial distribution of highly centralized agents, a proper coverage of network geography and place-based geography can be achieved in terms of communications (space of flows) and localized decisions (space of places).
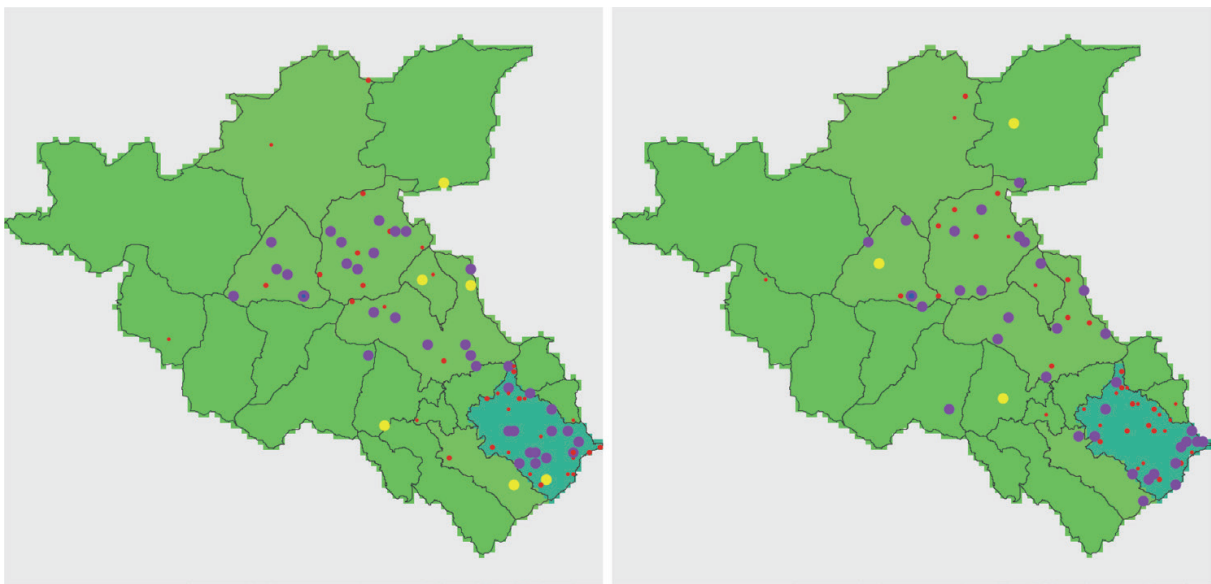
Figure 3. Distribution of agents with high betweenness centrality (yellow) and high closeness centrality (violet) for *numEvents* = 80 (left) and for *numEvents* = 8 (right) in the Steirische Eisenstrasse. Colors of municipalities indicate less than 2% of all projects (light green); between 2 and 20% (green); more than 20% (dark green).
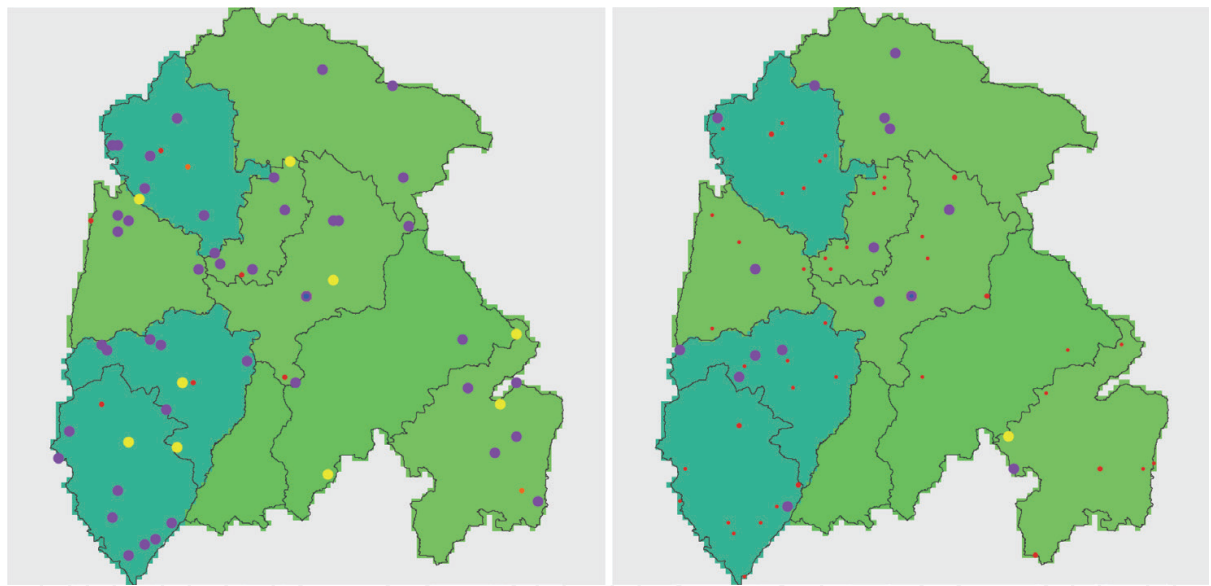

Figure 4. Distribution of agents with high betweenness centrality (yellow) and high closeness centrality (violet) for *numEvents* = 80 (left) and for *numEvents* = 8 (right) in the Mühlviertler Alm region. Colors of municipalities indicate: Less than 5% of all projects (light green); between 5 and 15% (green); more than 15% (dark green).

If this is true, then local projects can benefit from each other thanks to this type of knowledge dissemination. Ultimately, personal engagement in one's own local social environment also needs to be appreciated by rotating meeting locations across the entire region, because then "peripherally located" agents can act as hosts and can proudly present their project work in immediately visible form.

5. Conclusion

The basic intention of this contribution is threefold: first, and mainly, it attempts to emphasize the epistemological purpose of models and quantities as well as quantifications. This then implies a specific justification for the creation and utilization of models. Second, the chapter relates these reasons to a concrete methodological application, which was the translation of the qualities of the concept of social capital to a possible quantitative representation. This has been done by the core variable *number of face-to-face meeting opportunities* in a concrete empirical case study. Third, a geosimulation model is presented which aims to simulate the networking mechanisms within a definite parameter space in order to analyze the relevance of our core variable. Furthermore, the mutual relationship between a topology-based and a place-based space ought to be investigated.

Our concern was to establish an understanding of models and quantitative approaches which stress their adequateness in social scientific reasoning due to their characteristics in dealing with the subjects that matter. It has been argued that models do not refer to an absolute truth or reality that they do not represent or imitate reality but create their own reality and impact by their application within scientific communities. The hypothetical-constructivist realism appears to be a proper theoretical foundation to this argument. In fact, models and numbers attempt to make phenomena we observe or deduce theoretically tractable, graspable and visible. Since many social processes designed by models cannot be perceived straightforwardly or are unobservable in principle, it is the (communicative) relationship between model builders and model users that rewards their use, which is more important than looking for and looking at an intangible truth. "Occam's razor may still be the ultimate quest, but in many social systems, evident complexity is so great that plausibility rather than validity may be the real quest" [38].

The statistical and simulation results gained some plausibility to confirm our assumption that social capital can be represented by the quantitative measure of meeting events. However, further investigations are necessary. One issue is related to the composition of the empirical sample which has to be expanded to the team members in order to detect potential connections among this group. Consequently, the structure of the original social networks can be better represented in the geosimulation network model (the issue of calibration). Another still existing problem is the one-dimensional re-presentation of social capital. An incorporation of further sorts of capital (economic, cultural) would lead to an empirically more reliable model because of the consideration of mutual correlations between them. This, in turn, would improve the model results which influence our understanding of the empirical reality (the issue of verification and validation). Finally, the geographical context—in its two dimensions of topology and chorology—ought to be investigated more deeply. What interdependencies between networks and places in terms of spatial proximity and center-periphery relationships might have an impact on the size and composition of the network, and the distribution of actors on the allocation of social capital, should be further discussed. Though an integration of these issues will definitely improve our understanding and imagination of social networks which take social capital explicitly into account, the geosimulation model presented here justifies the continuation of research on this scientific path.

Acknowledgements

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