Interdependencies and synergies between urban public transport systems and the built environment: framework for system analysis

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Abstract

Urban public transport systems and their built environment are interwoven in various ways and on various scales. These strong interrelations offer a large potential for creating mutual benefits, but they can also be a cause for undesired effects. While such reciprocal effects have been described by various authors, a systematic approach to the identification and activation of potential synergies involving small scales is lacking until now.

This is why a framework for the systematic analysis of interrelations between urban public transport systems and their built environment will be developed, considering different scale levels and cross-scale effects, as well as the effects on quality. The framework is based on a system elements interrelations model and will be the fundament for the combination of existing knowledge and new insights from own analyses and observations.

The system elements interrelations model will be used to identify potential synergies between urban public transport systems and their built environment. Ultimately, the model could help to overcome existing conflicts in planning and foster the successful combination of urban qualities with efficient, reliable and safe public transport systems.

This article presents the background of and motivation for the project as well as the current state of the interrelation model and also explains next steps. It is of conceptual nature.

Keywords

public transport – built environment – urban quality – synergy – spatial development – urban planning – infrastructure – urban insertion of public transport systems

1. Introduction

“Mass transit needs masses”[1], that is public transport supply quality largely depends on activity density. Density, on the other hand, is often at the core of current debates on sustainable cities in Switzerland and elsewhere and related land-use policies. Within dense settlements, public and road space are usually scarce, while transport demand is spatially concentrated. Therefore, this demand can often only be met with transit due to its space efficiency when compared with the private car. Hence, public transport not only benefits from density, but conversely is also a prerequisite for dense structures in many cases, or: “masses need mass transit”.

The acceptance and success of dense urban settlements depend on the creation and consolidation of urban quality – as for example stated by Angélil et al. (2013) within the Swiss National Research Programme 65 “New Urban Quality”. Urban quality also has further importance: A high quality built environment serves sustainability goals directly – e.g., it strongly affects individuals’ field of possibilities and hence aspects such as social equity and accessibility, but also travel behaviour; furthermore, it is a locational factor for economy and tourism (German EU Presidency, 2007).

The built environment affects public transport systems not only by means of user density, but in various ways, e.g. by urban patterns, the allocation of public and road space, and access path networks to transit stops, among many others. In turn, public transport systems affect the development and shape of cities, and they directly and indirectly influence urban quality. In fact, public transport systems are often seen as a key element in achieving more sustainable and liveable cities, and there are numerous examples of transit’s contribution to urban transformation processes.

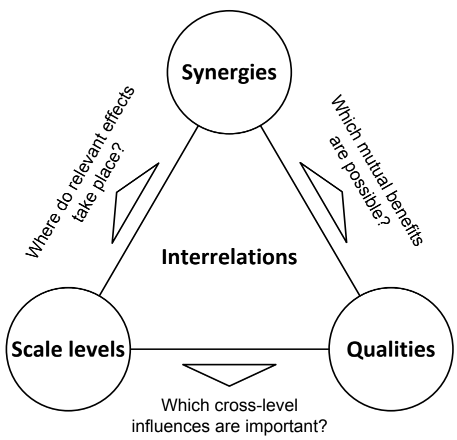
To sum it up, there are strong interrelations between urban public transport systems and their built environment, and large potential synergies exist. However, a stroll around any city is enough to realize that in some cases, mutually beneficial effects are not appropriately uzilized – a strong contrast to cases where e.g. new tram lines were successfully used for urban upgrade. Despite the magnitude of effects a successful and deliberate use of interrelations can have, there is surprisingly little systematic application of such approaches. One reason for this seems to be the lack of systematic knowledge regarding some aspects within this context.

[1] Unfortunately, it was not possible to identify the original source of this common saying, used e.g. in Suzuki, Cervero and Iuchi (2013), p. 15, 50 and 173.

The interrelations between urban public transport systems and their built environment are diverse. Extensive research has been conducted on the mutual influences of transport and land use on large scale levels (e.g. Newman and Kenworthy (1989), Ewing and Cervero (2010)), on the general influences of public transport on the built environment and vice versa (e.g. Babalik-Sutcliffe (2002), Currie, Ahern and Delbosc (2011)), and on the integration of land use and transport (e.g. Cervero and TRB (2004), Bertolini, le Clercq and Kapoen (2005), Curtis and Scheurer (2010)). The small scale, however, is usually only marginally considered. The importance of elements such as pedestrian access to public transport may be acknowledged, but rarely are real implications examined down to the pedestrian perspective. On the other hand, the importance of transportation infrastructures, especially streets, as well as walkability, for urban quality has long been established (e.g. Appleyard (1981), Jacobs (1993), Holzapfel (2012), Adkins, Dill, Luhr and Neal (2012)). Reversely, small scale elements of the built environment also affect public transport (e.g. Filion, McSpurren and Appleby (2006), Suzuki, Cervero and Iuchi (2013)). In disciplines such as urban design, small scales are carefully examined, but then, in those cases transport systems are usually only marginally considered, without explicitly examining their potential (e.g. Angélil et al. (2013)).

The knowledge in different disciplines and concerning different scale levels and aspects within this context so far has not been systematically combined, and potential for synergies can usually only be identified regarding specific aspects. This is why a framework for the systematic analysis of interrelations between urban public transport systems and their built environment will be developed, considering different scale levels and cross-scale effects, as well as the effects on quality. The project is summarised in Figure 1.

Figure 1 Project overview



Source: Own depiction

Ultimately the project seeks to examine how public transport systems contribute to the creation and consolidation of urban quality, and how they, in turn, are affected by the built environment and its development.

More specifically, the following objectives are to be achieved with the project:

- To systematically detect, understand and quantitatively or qualitatively describe interrelations within the system urban public transport – built environment.
- To identify predominant elements and interrelations within this system.
- To develop and integrate a suitable concept of scale levels.
- To operationalize quality concepts for both urban public transport and the built environment.
- To develop a corresponding analysis method for interrelations and mutual effects.
- To adapt and use the analysis method for the systematic identification of synergy potential.
- To derive recommendations on combination of elements and identification and activation of synergies.

The project is limited to the examination of combinations of physical elements and system properties, and the outcome in terms of quality. It will not consider context issues such as policies and politics, planning and decision-making processes, legal frameworks or stakeholder interests.

This article is based on an early-stage PhD project at IVT and related project proposals, and is therefore of conceptual nature. It is structured in three parts. The background of the project and its significance are exemplified with reference to relevant literature. Next, the research concept is summarised and the proposed framework for system analysis introduced. The article ends with a short outlook.

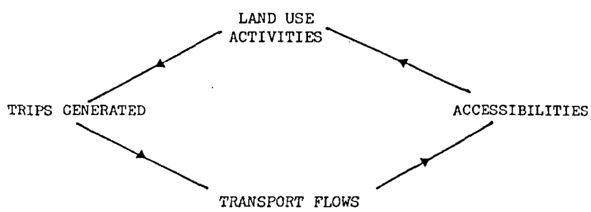
2. Background

2.1 Interrelations between transport and the built environment

2.1.1 Interrelations at a large scale

Interrelations between transport and the built environment have been extensively researched for a very long time. For example, more than 100 years ago, Hurd (1903) examined the influence of proximity and accessibility on land value and directions of urban growth. Similarly, Hoyt (1939) described how transportation lines structure the growth and shape of cities. Models of land use were developed based on the effects of accessibility on urban development (e.g., Hansen (1959)), and cyclical relationships considered (see, e.g., Mackett (1985) as depicted in Figure 2). There are many efforts ongoing for an adequate model representation of these interrelations (for an overview, see e.g. Zöllig, Hilber and Axhausen (2011)). Similarly, the influence of the built environment on travel behaviour has been extensively researched: Ewing and Cervero (2010) found more than 200 individual studies on this topic.

Figure 2 Cyclical relationship between land use and transport

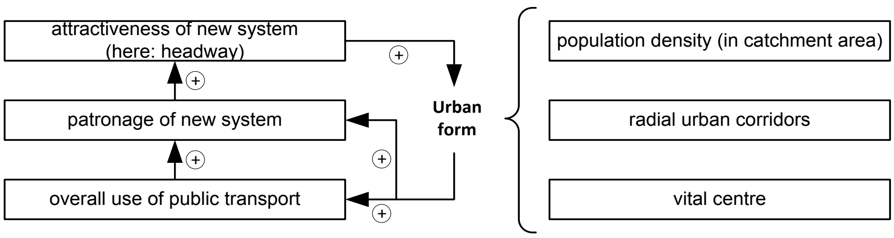


Source: Mackett (1985), p. 326

More specifically, the effects of public transport systems on urban space, its quality and development, have also been examined by various scholars. Again, Hurd (1903) provides an early example; he examines three ways in which “steam railroads affect city land” (p. 60): (1) terminals as attraction points, also creating axial effects in local transport; (2) line as barrier to growth or communication; (3) line as influence on adjacent land. Based on an analysis of the influence of public transport on the development of cities – in particular, land use and settlement patterns – Lehner (1966) calls for a strong link between dense urban development and public transport, mostly due to the dependency of dense settlements on transport capacity. To this effect, the comparative advantage in space efficiency of public transport when compared to the car has been repeatedly demonstrated, maybe most strikingly with the use of pictures such as those published in Wacker (1992). Public transport projects, particularly in the case of light rail transit (LRT), are often seen as a key factor for urban renewal or regeneration programmes, as for example described by Besier (2011), Kaminagai (2013) and Walton (2013). A deliberate use of public transport systems to increase the attractiveness of urban space is demonstrated in theory by Jansen, Garde and Schmidt (2013). German EU Presidency (2007) emphasizes the role of public transport for social equity and just accessibility in disadvantaged areas.

Reversely, urban form strongly affects public transport systems. As Babalik-Sutcliffe (2002) states, "impact of urban form on the performance of urban rail systems is a broad area of agreement in the literature" (p. 442). Among drivers of ridership for different public transport systems found by Currie et al. (2011) and Currie and Delbosc (2011) are employment density and street / track layout (i.e., segregation). Babalik-Sutcliffe (2002) also describes influences of public transport systems on urban form, and some cases of mutual reinforcing effects. One such example, based on his description, is depicted in Figure 3.

Figure 3 Example of mutual reinforcing effects between public transport and urban form



Source: Own depiction, based on description by Babalik-Sutcliffe (2002), p. 427 and 442

2.1.2 Interrelations at a small scale

Numerous scholars have examined the influence of car traffic and roads on liveability and urban quality. The large portion of space in cities used for transport – mainly in the form of streets – was early recognized (e.g. Mayer (1969)). This is of particular importance given that "streetspace forms the basic core of all urban public space" (Marshall (2005), p. 13). Appleyard (1981) emphasizes the importance of streets for liveable places and describes their double role as living space and channels for transport and access, as well as the inherent conflicts. Jacobs (1993) has a similar claim: "Streets more than anything else are what make the public realm. […] If we do right by our streets we can in large measure do right by the city as a whole – and, therefore and most importantly, by its inhabitants." (p. 314). For Holzapfel

(2012), the relationship street – forecourt – building is of great importance, as it defines possible uses and thus diversity and also strongly affects urban quality and walkability. For him, only a combination of urban design and transportation measures can impede the growth of car traffic and foster mixed-use, attractive surroundings. Thus, he calls for a reconciliation of urbanism and transportation, explicitly including small scale elements. Similarly, in order to achieve high quality and walkable urban spaces, the Irish Design Manual for Urban Roads and Streets (Lahart et al., 2013) calls for a combination of urban design and traffic engineering with a focus on small scales. More specific, Adkins et al. (2012) report a high influence of "micro-scale built environment characteristics" on the perception of walking environment attractiveness. The built environment, especially road layout, also strongly affects traffic safety, which in turn influences urban quality. Millot (2004; 2008) describes small scale effects of road improvements and associated elements of the built environment on safety, highlighting interrelations and sometimes unwanted results.

These few examples of a vast array of publications of similar nature support the notion that the small or pedestrian scale is highly relevant when analysing interrelations between transport systems and their built environment. Public transport is linked to these issues because in some constellations, public transport supply can reduce car traffic, and hence mitigate some of the adverse effects of the latter on urban quality. But additionally, there are also direct interrelations between public transport systems and the built environment at a small scale. Moreover, cross-scale effects also occur. One important example: Public transport is highly dependent on pedestrian access to stops, while the quality of urban spaces is highly influenced by walkability. Grob and Michel (2011) show dependencies of pedestrian networks on urban structures and small scale elements and their importance for access to public transport. Other influences of urban design at the neighbourhood and street level are described by Suzuki et al. (2013). They stress the importance of small-scale elements of the built environment for both its quality and the success of respective public transport systems, as well as for the connection between a transit system and its surrounding neighbourhoods. Filion et al. (2006) point out the influence of medium scale (e.g. local activity range or commercial streets) as well as large scale factors (e.g. matching of high density with high quality public transport) on walking.

2.2 Integration of transport and land use

Given the evidence of interrelations between transport and the built environment, the concept of integrative planning comes as no surprise. In fact, it has been around for a very long time. For example, Mayer (1969) summarizes the efforts for "comprehensive planning" in the USA in the 1960ies. Today, integration of land use and transport is seen as a key for sustainable urban development and in many cases is an accepted policy principle. Among others, the

Leipzig Charter (German EU Presidency, 2007), with the aim of high-quality urban spaces, calls for an integrated urban planning including infrastructure and transport. Integration is also an important principle in Swiss spatial development concepts (UVEK, 2012).

In many cases, statements on integration remain vague and general, without clear conclusions about concrete actions or policies. On the other hand, approaches for operationalization of integration in planning and activation of related synergies do exist, with successful applications. Two common examples are transit-oriented developments (TOD) (e.g. Calthorpe (1993), Cervero and TRB (2004)) and planning for accessibility (e.g. Bertolini et al. (2005), Curtis and Scheurer (2010)).

While these and other integrative approaches are certainly valuable, justified and pointing in the right direction, they normally lack a thorough consideration of the small scale. Even though the importance of factors such as walkable neighbourhoods or accessible public transport stops is repeatedly stressed, these aspects and related interrelations are rarely examined in detail within integrated approaches. True integration, however, can only be achieved considering these very aspects, together with larger scales.

In urban design, on the other hand, the small scale is carefully considered. However, transport systems are often only implicitly considered as part of urban space and influencing urbanization processes, without specific examination of their role within this context, e.g. their potential of activating urban qualities and synergies, but also possible negative interactive effects. Angélil et al. (2013), for example, identify numerous deficits in urbanized spaces, and state that potentials for urban quality are often not recognized. Coherently, they call for the holistic examination and design of urban space, in order to recognize and activate potential for synergies. Transportation, though, is only marginally considered.

There are, however, cases of successful integration including the small scale, as for example described by Hamilton-Baillie (2004) regarding general transportation or Schrempf (2013a; 2013b) with a focus on public transport. More examples include recommendations for LRT infrastructure combining a technical and urban design perspective derived by Besier (2013) from successful cases, or successful transit orientation in Copenhagen and Stockholm described with an emphasis given to the combination with pedestrian-friendly public spaces on very small scales by Suzuki et al. (2013). However, the mentioned articles do not analyze elements and their interactions systematically, but rather describe their importance and overall results.

The authors' participation in COST Action TU 1103 "Operation and safety of tramways in interaction with public space", as well as in consulting projects, led to interesting opportunities for exchange with public transport operators and consulting practitioners in the field of public transport planning and safety. One general finding is that despite the repeated claims of integrated planning, in many cases there seems to be insufficient application of holistic approaches in practice when addressing planning tasks for urban settings in conjunction with public transport systems. Disciplinary boundaries and the defense of particular interests by stakeholders limit the possibilities for achieving the overall best possible result and obstruct the activation of synergies, sometimes rendering inefficient solutions. Projects' outcomes seem to depend strongly on expert knowledge, which in some cases can hinder the interconnection of knowledge about related, but usually separately treated aspects of planning.

2.3 A systematic approach to synergies is needed

The studies and examples mentioned above demonstrate three main points. Firstly, interrelations between urban public transport systems and their built environment do occur on different scale levels, including small scales, and the respective effects are important for both the quality of public transport as well as urban qualities; synergies, but also undesired mutual reinforcing effects do occur. Secondly, interrelations on small scales are normally not systematically considered in detail in integrated approaches. There are examples of successful integration including small scale elements, but respective publications are usually of more descriptive rather than analytical nature. Thirdly, shortcomings in practice are at least partially caused by lack of systematic and accessible knowledge about the above mentioned interrelations.

Therefore, a systematic approach to synergies between urban public transport systems and their built environment including insights from different disciplines and, most importantly, accounting for different scale levels and cross-scale effects, is both needed and promising.

3. Framework for system analysis

3.1 Project overview

In order to achieve a systematic identification and activation of synergies between urban public transport systems and their built environment, a detailed and holistic understanding of elements and interrelations involved is needed. Currently, no framework for such a holistic and systematic analysis exists, despite the vast array of studies on interrelations between transport and built environment. Therefore, this project will develop a system analysis framework, based on a system elements interrelations model, including an adequate concept of scale levels. At a later stage, the model will be applied to case studies as a proof-of-concept, and conclusions about its quality and applicability will be derived. This article, however, will focus on the current concept for the interrelations model.

The system interrelations model will be the framework used to combine knowledge from different, primary and secondary, sources and for the systematic analysis of interrelations, regarding qualities, synergies and scale levels. The broad range of literature and other sources mentioned above will provide a strong base for identifying relevant elements of both the built environment and urban public transport systems, as well as relations between these elements. They will be complemented with additional studies where gaps are identified.

The following sections will describe the current conceptual state of the model as well as potential sources and challenges.

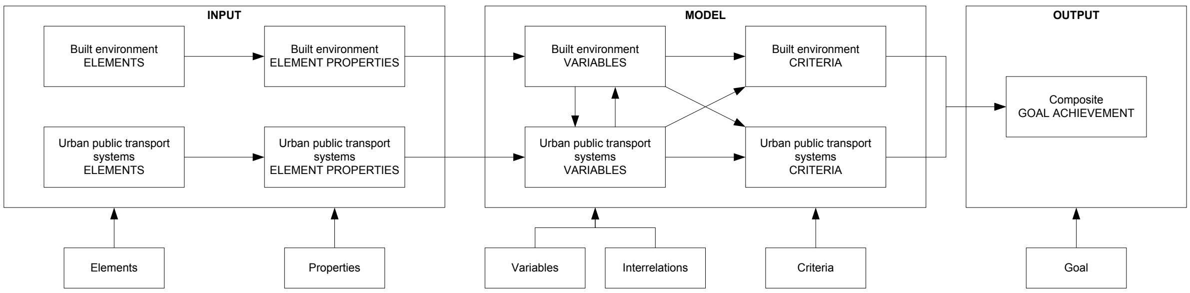
3.2 System elements interrelations model

3.2.1 Model summary

Figure 4 summarizes the model concept. The model input is constituted by elements of urban public transport systems and the built environment and their properties. Within the model these elements' properties are represented as generic variables. Interrelations can occur between variables. The result of a specific combination of variables and their interrelations is measured with quality criteria, each of them influenced by one or several variables. The criteria are weighted and combined into a composite goal achievement score. This goal achievement score has no unit and mostly allows for an overall comparison of different alternatives or the assessment of incremental changes. By ways of changing weights, it is adaptable to specific context and circumstances.

The values for each variable and each criterion provide a detailed understanding of effects within the system and between elements and are needed for a detailed analysis, e.g. of causal relationships.

Figure 4 Conceptual overview of the system elements interrelations model

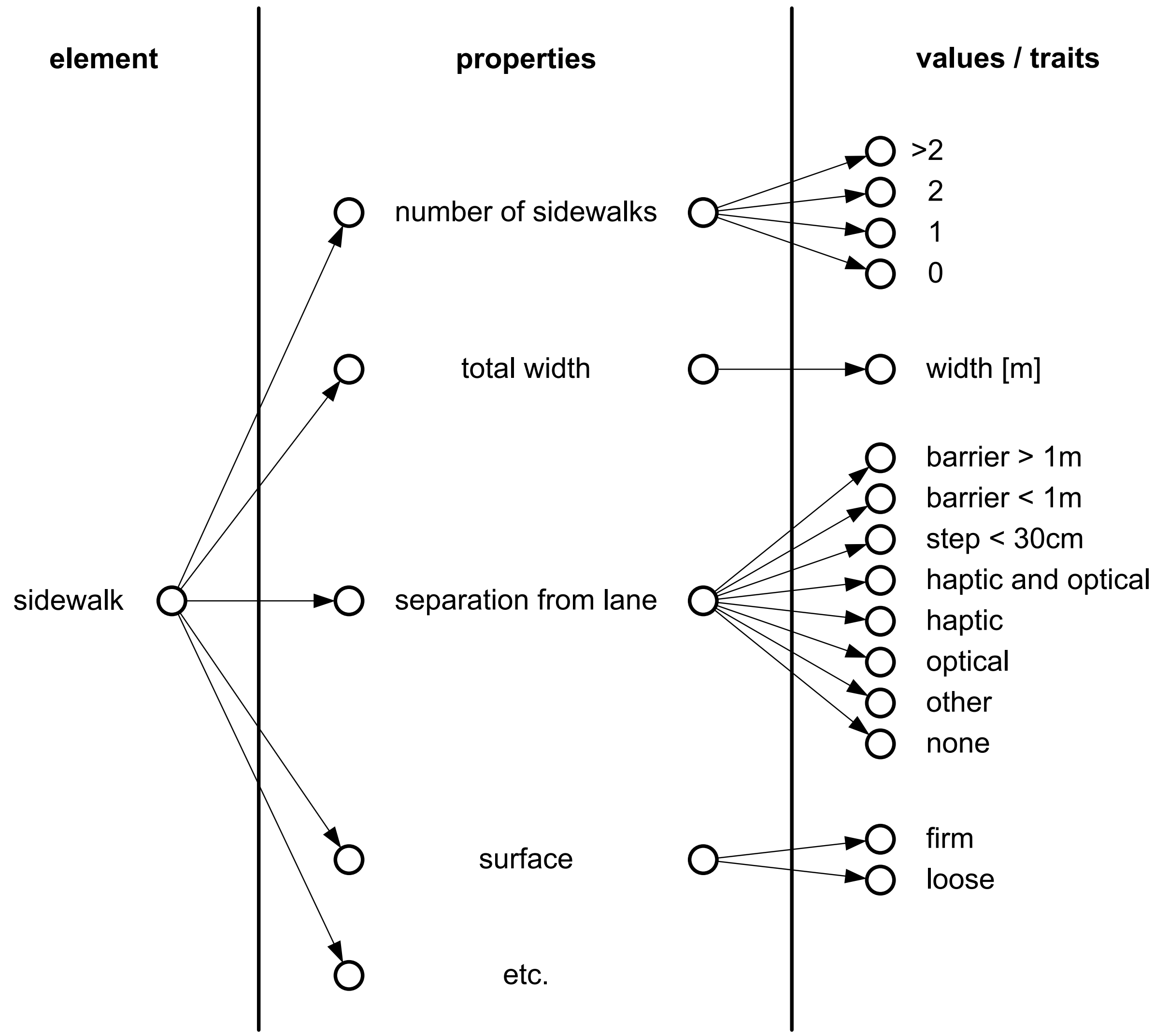


Source: Own depiction

3.2.2 System elements, properties and values

As a first step, a systematic collection of elements of urban public transport systems as well as the built environment that could be relevant within the projects' scope will be compiled. For each element, properties and possible values or traits will also be recorded. An example is depicted in Figure 5.

Figure 5 Example of system element (sidewalk), properties and values / traits



Source: Own depiction

The collection of elements, properties and possible values or traits will be based on an extended literature review, on interviews, previous work by the authors and on observations. Examples of potential sources and their content are summarized in Table 1. This knowledge base will be extended during the course of the project. Furthermore, the evaluation of variables and criteria (see below) might render some elements relevant that have not been included initially.

Table 1 Potential sources for the identification of elements

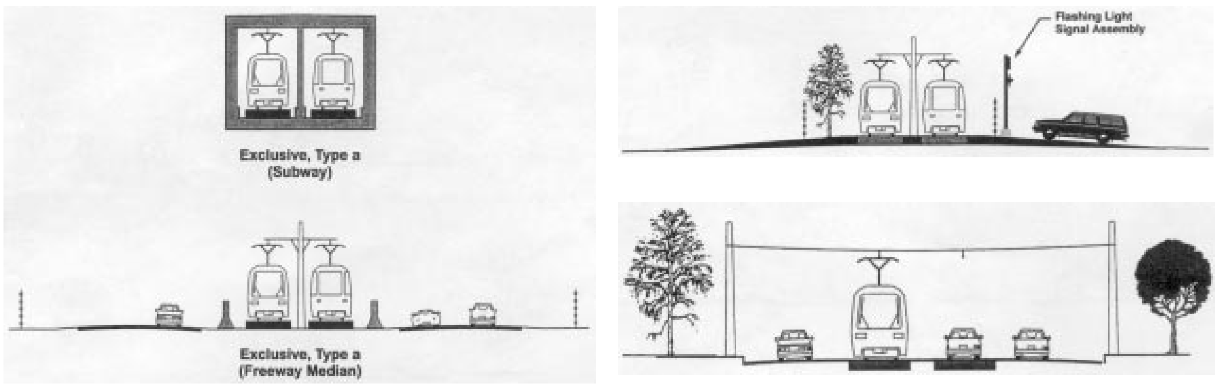
Source	Content	Description / elements and properties
Koltsova, Kunze and Schmitt (2012)	Urban design parameters used in parametric design approach	Street profile: spatial width; street width; moving lanes; parking lanes; sidewalk width; proportion street wall; proportion sky Block: block dimension; lot width; lot depth; lot coverage Facade: First floor above grade Open space: Number of courtyards, plazas, and parks; noise level Vegetation: Proportion of native vegetation; connectivity of green and open spaces
Weidmann, Dorbritz, Orth, Scherer and Spacek (2011)	Properties of public transport systems	Systematic collection of properties of different public transport systems
STRMTG (2010)	French tramways infrastructure codification system	Urban environment Station characteristics Running section characteristics Intersection characteristics
Millot (2004)	Properties of urban form	Road network organisation Distribution of road users in public space Public space organisation Visual characteristics of the road environment Parking space organisation Arterial road layout
Thiis-Evensen and Nybo (1999)	Elements of the built environment	Street types Street form Street walls Street floor
Alexander et al. (1981)	Patterns	Extensive collection of patterns on different scale levels based on observations, with very opinionated conclusions about each element concerned.

3.2.3 Variables

In order to ensure applicability in a broad range of cases and to provide sufficient flexibility for the integration of knowledge from various different sources, the model must be as generic as possible, while still featuring enough specificity for application in concrete cases. For this reason, system element's properties are represented by generalized variables in the model, reducing very specific aspects of reality to more abstract representations. Each variable has a value and attributes. Using different scales for values – including nominal and ordinal scales – will allow for the consideration of aspects that can only be assessed qualitatively. Attributes include, for example, minimum and maximum values and unit where appropriate.

For example, the element public transport system lane, and properties such as form of segregation, places where other road users can cross the lane, and possible operational speeds could be summarised using right-of-way types according to the classification system suggested by Korve et al. (1996) (right-of-way types: a, b1 – b5 and c1 – c3, see example in Figure 6). Thus, only the variable right-of-way type would appear in the system elements interrelations model, but not the exact type of physical segregation used. Many more similar abstractions and simplifications are possible based on literature and observation.

Figure 6 Examples: public transport right-of-way classification a (left), b1 and c1 (right)



Source: Korve et al. (1996), Figures 2-2, 2-3 and 2-8

Apart from variables derived from elements and their properties, more abstract measures will also be included as variables, such as, for example, reliability of public transport systems: it depends on some and simultaneously affects other variables, but cannot be linked directly to one single element's properties.

3.2.4 Interrelations

There are three major types of interrelations between variables to be distinguished:

1. constraints,
2. dependencies, and
3. influences.

Each relationship has a set of attributes:

- direction,
- description, and
- time lag.

For each interrelation, an adequate form of description will have to be established, among other things depending on type. For example, for constraints, the definition of a solution space might be appropriate, whereas elasticity might describe influences, and a function could be more suitable to represent dependencies.

Again, literature research and previous work will be important sources, because for many of the relationships concerned, there are studies delivering sufficient information for direct application in the model. Examples are the responsiveness of public transport users relative to distance from stops ("Ansprechbarkeitskurven"), as described by Walther (1973), influences on urban public transport operation examined by Weidmann, Orth, Schwertner and Nägeli (2013) or Naegeli, Orth, Weidmann and Nash (2013), or influences on quality, stability and reliability of urban public transport systems (Carrasco, 2012; Carrasco, Fink and Weidmann, 2012), as well as some of the examples mentioned in section 2. However, these sources will have to be extended with new analyses and observations where gaps occur. Some promising approaches with prior application according to literature include statistical models (e.g. regression analysis), correlation analysis, comparative analysis, observation and expert interviews.

3.2.5 Quality

Model outcomes, for example for different project alternatives, will be compared and evaluated using a composite measure for the "goodness" of the built environment and the respective urban public transport system. The approach is a linear combination of quality criteria with weights for both fields in a goal achievement score. Thus, relative comparisons will be possible. The appointment of weights to criteria will be dependent on context and specific needs, and could for example be executed using a common multiple-criteria decision analysis method, such as the analytic hierarchy process.

The quality criteria should cover generally accepted aspects reflecting quality of the built environment and of public transport systems. Even though there certainly is no unanimous definition for quality, particularly concerning the built environment, it seems feasible to define a set of criteria that reflects a broad range of opinions. The main sources for the definition of criteria and the identification of appropriate indicators will be an extended literature review, and to some extend expert interviews. The use of specific indicators may also necessitate the modification of some variables used.

Regarding public transport system, the quality criteria will be largely based on previous work by the authors and other members of their research group, namely on aspects such as Level of Service of public transport or reliability (e.g., Orth, Weidmann and Dorbritz (2012)). For the quality of the built environment, there are many quality concepts in literature. Table 2 shows some examples.

Table 2 Some examples for quality concepts for the built environment

Source	Area	Criteria
Lynch (1981)	Performance of urban space	“dimensions of performance” for cities: Vitality; sense; fit; access; control; efficiency; justice
Jacobs (1993)	Streetscape	“Requirements for great streets”: Places for people to walk with leisure; physical comfort; definition; qualities that engage the eyes; transparency; complementarity; maintenance; quality of construction and design
		“Qualities that contribute to great streets”: Trees; beginnings and endings; diversity; details; places; accessibility; density; length; slope; parking; contrast; time
Burns (2005)	Urban qualities	Character; continuity and enclosure; convivial public realm; ease of movement; legibility; adaptability; diversity and choice
Grob and Michel (2011)	Walkability	Directness; comfort; obstacle free; low gradient; attractiveness; small mesh size; continuity
Koltsova et al. (2012)	Urban qualities	Accessibility; accessibility of green areas; degree of openness; permeability of the edges; imageability; legibility; enclosure; linkage
Angélil et al. (2013)	Urban qualities	Centrality; accessibility; usability; adaptability; appropriation; diversity; interaction
Lahart et al. (2013)	People friendly streets	Connectivity; enclosure; activity edge; pedestrian activity/facilities

3.2.6 Scale levels

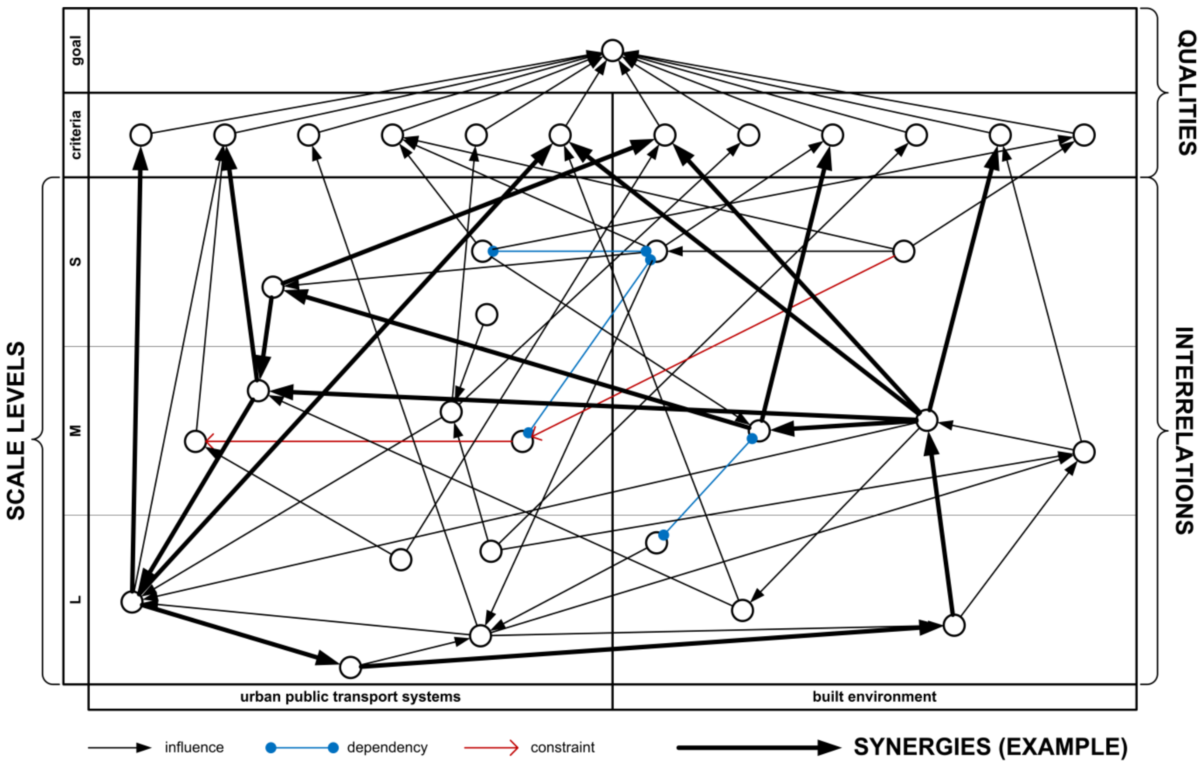
As previously mentioned, a concept for scale levels will have to be developed in order to explicitly incorporate small-scale elements and related interrelations and to adequately represent cross-scale effects within the model. This concept will be based on the following preliminary levels:

1. Small scale: the pedestrian perspective, defined by visibility from any given point.
2. Medium scale: catchment area of a public transport station or stop.
3. Large scale: transport / urban corridors up to network / large areas.

3.2.7 Model overview: where are the synergies?

The combination of variables, interrelations, criteria and goals in the system elements interrelations model is indicated in an abstract, conceptual manner in Figure 7. It provides a generic example of reciprocal influences affecting the quality of both the built environment as well as public transport (highlighted interrelations), composing a feedback loop. In order to holistically understand results of positive and negative mutual effect and to identify potential synergies, the consideration of indirect influences via other variables, including those of the other field, is crucial.

Figure 7 Model overview



Source: Own depiction

The temporal dimension or dynamics of developments will be analysed using the relationship attribute "time lag". The stepwise analysis of variables' values will be used to observe changes within the system over time.

4. Outlook

This article presents the concept for a framework for the analysis of the system urban public transport – built environment. This framework will have to be further developed, literature will be thoroughly analysed to find useful results and new analyses will be conducted. A major challenge for the project is the integration of insights and data from various sources, particularly because there is a diversity of methods and types of descriptions used by other authors, especially regarding interrelations.

However, this integration of knowledge from diverse sources from different fields is also one of the main contributions of the project. Guided by the proposed framework, knowledge that today is not usually considered as connected will be combined and form a comprehensive base for the analysis of interrelations and the identification of synergies. This will enable practitioners to identify the decisive elements within the system and put adequate focus on them, without losing the big picture and without ignoring the complex web of interrelations with other elements.

Broadly speaking, four main areas of model application are foreseen and will be exemplarily demonstrated at a later stage of the project: analysis, comparison of alternatives, suitability check, and identification of potential improvements. The different parts of the framework, e.g. the systematic collection of elements or the operationalization of quality concepts, will provide useful insights on their own, particularly for teaching activities.

The next steps will be as follows: in parallel, a broad literature review on the aspects described in section 3.2 will be conducted, and a strongly simplified version of the interrelations model will be implemented. The latter will provide valuable inputs to refine the methodology and to further delineate the project due to feasibility, while the former will provide the base for the extended version of the model to be implemented subsequently. Furthermore, it will clarify research gaps that necessitate further studies on interrelations, and point to methods suitable for those specific cases.

5. References

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