Typo-morphological diversity and urban resilience: a comparative study of three heterogeneous blocks in Brussels

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Abstract. *Mixed-use heterogeneous urban fabrics have been shown to be more adaptable to continuous urban change than mono-functional homogeneous ones. More specifically, studies on high street cases have highlighted the positive role of 'morphological mix' for maintaining a continuous balance between urban robustness and adaptability, which is a definition of urban resilience. However, the particular linear condition of high streets allows only for a partial analysis of typo-morphological synergies within complex adaptive processes. This paper investigates how typo-morphological diversity (TMD) affects the adaptive process of urban fabrics facing contextual changes in the case of three central heterogeneous urban blocks along the canal in Brussels. These urban blocks are characterized by a high degree of TMD at street, plot and building levels and by significant changes through time in all of these typo-morphological components. A comparative morphogenetic analysis c.1866–2022 reveals that, while undergoing similar contextual changes, the specific spatial configurations of each block have led to different morphological transformations. However, beyond the specificities of each block, the comparative analysis highlights recurrent typo-morphological processes and reveals the particular impact of public space status and design on TMD development and evolution.*

Keywords: typo-morphological diversity, urban resilience, adaptive cycle, heterogeneous urban fabrics, Brussels

Introduction

Cities are dynamic and complex socio-ecological systems in constant evolution (Chelleri, 2012; Marcus and Colding, 2014; Salat *et al.*, 2011; Tjallingii, 1995). Consequently, both scholars and practitioners have demonstrated the necessity to develop alternative modes of urban development and planning including volatility, uncertainty, complexity and ambiguity (Bergevoet and van Tuijl, 2016; Durand and Paquot, 2017; Salat, 2017; Verebes, 2013). Moreover, the actual economic crisis coupled with the environmental crisis has given rise to adaptive urban strategies towards the renovation, revitalization and recycling of obsolete or declining urban areas and components (D'Arienzo and Younès, 2014).

Within this perspective, the concept of resilience, extrapolated from socio-ecological systems theory (Holling, 1973), has been

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proposed to meet the challenges of changing cities (Chelleri, 2012; Marcus and Colding, 2014; Toubin *et al*, 2012). Initially related to the vulnerability of urban systems facing catastrophic events, the urban resilience concept has recently been correlated with the capacity of a built environment to tackle ordinary crises (Feliciotti, 2015; Garcia and Vale, 2017). When associated with the objective of sustainability, urban resilience refers to the ability of urban systems to adapt to change without limiting current and future adaptive capacity (Meerow *et al.*, 2016). In other words, urban resilience is regarded as the capacity of an urban system to maintain a continuous balance between urban robustness and adaptability.

Within this field of studies, urban diversity has been shown to be a key attribute of urban resilience (Feliciotti *et al.*, 2017; Hassler and Kohler, 2014; Marcus and Colding, 2014). Comprising a mix of formal, functional and social mixes (Wood and Dovey, 2015, p. 65), urban diversity is crucial to urban adaptation and innovation (Ahern, 2013; Dovey *et al.*, 2018; Jacobs, 1961). Regarding urban form, this outcome echoes Conzen's earlier observation that a great diversity in the plot pattern and associated buildings offers 'differential resistance' to a plot series development (Conzen, 1960, p. 96). In other words, if 'differential resistance' means allowing for a mix of robustness and adaptation, what we suggest should be termed 'typo-morphological diversity' (TMD) becomes a key factor conditioning urban resilience in general.

From this hypothesis, the aim of this paper is to deepen the current understanding of the correlation between TMD and urban fabric adaptive capacity to contextual changes, first by examining earlier theories and research in the field, and secondly, by comparing the adaptive cycle of three dense heterogeneous urban blocks along the canal of Brussels. These urban fabrics were originally characterized by a similar organisation of their morphological components – streets, plots and buildings. Afterwards, despite a similar evolution of the social and economic context, they have undergone significantly different morphological developments and transformations. This inductive work sheds light on the historical and inter-scalar synergies occurring between urban fabric components. Doing so demonstrates how typo-morphological properties affect robustness and adaptability in heterogeneous urban fabrics.

Theoretical framework

Resilience in the urban form

The concept of resilience is defined by the capacity of a system (an ecosystem, a habitat, a population) to cope with external changes while maintaining its structure, functions and identity (Holling, 1973). As a systemic approach, the concept of resilience recognizes continuous change within complex adaptive systems (Holling, 1973; Holling *et al.*, 2002), such as urban systems (Chelleri, 2012; Hassler and Kohler, 2014). Therefore, urban resilience is characterized by the long-term robustness of the urban system through the short-term adaptability of its components (subsystems or subassemblies) (Chelleri, 2012; Salat, 2017). Applied to the urban form, which is considered as a component of the urban system (Meerow *et al.*, 2016), urban resilience offers to urban morphologists a conceptual frame for evaluating urban fabric adaptive capacity (Feliciotti *et al.*, 2017; Salat, 2017). Within this field of study, research has highlighted the specific robustness and adaptability to change of major components of urban form (Conzen, 1960; Vernez Moudon, 1986), namely the streets, the plots and the buildings (Vernez Moudon, 1997). Indeed, the transformation of the street network is less likely to occur than the adaptation of building and plot patterns (Caniggia and Maffei, 2000; Conzen, 1960, 1975). Buildings are the most fragile components with a linear development process composed of construction, use, modification and finally demolition phases (Kropf, 2001, p. 35). This outcome leads us to investigate urban fabric adaptive capacity through the lens of the transformation of urban form components.

Typo-morphological diversity (TMD)

Urban diversity is another factor in 'differential resistance'. First defined by Jane Jacobs (1961) as a mix of building age and a mix of function associated with density and permeability, urban diversity has recently been proven to be a key feature in opening up opportunities for dealing with change and adaptation (Ahern, 2013; Dovey *et al.*, 2018; Hassler and Kohler, 2014; Marcus and Colding, 2014). However, the concept of urban diversity is often narrowed to a measure based on the distribution of land uses (Dovey *et al.*, 2018; van den Hoeck, 2008). The limit of that approach is that land use is a highly fluctuating element unlike more resistant urban form components (Conzen, 1960, p. 6). Recent works have therefore stressed the importance of considering the 'spatial diversity' in the street system (Marcus and Colding, 2014, p. 54) and the 'morphological mix' inside urban fabrics (Wood and Dovey, 2015, p. 65) within the urban resilience conceptual framework. We propose to merge these two concepts into a new one called 'typo-morphological diversity' (TMD) which is characterized by a simultaneous diversity in street, plot, building and public/private interface types inside the urban fabric and street front, as represented in Figure 1. The TMD concept allows for deeper analysis of how urban diversity affects the adaptive capacity of urban fabric.

Adaptive cycle

A great deal of research has shown that the urban form experiences cyclical periodic changes (Kropf, 2001) resulting from the simultaneous and interactive action of socio-economic processes and political decisions on spaces affected by topographical, cultural and urban heritage (Allain, 2004). In the field of urban morphology, these cycles are understood as the product of complex inter-scalar synergies between morphological components themselves and upper scale change processes (Allain, 2004; Feliciotti *et al.*, 2018).

Studying the formative and transformative processes in Alnwick at urban fabric and plot series levels led Conzen (1960) to the concept of 'burgage cycle'. Subsequently observed in other urban and historical contexts (Koter, 1990; Ünlü and Baş, 2017), this plot cycle is composed of four phases: institutive, repletive, climax and recessive (see Figure 2a). At the scale of the street front, the completion of the cycle corresponds to an urban fallow with temporary voids establishing the initial stage for a future redevelopment cycle (see Figure 2b, after Conzen, 1960, p. 94). The plot cycle completion is a complex process depending on a few interrelated factors. First, the 'morphological period' – and its related socio-economic context, during which the urban fabric has been developed and transformed – influences the street system configuration, plot pattern and building types as well as land use patterns (Conzen, 1960, p. 7). Secondly, the location of the street front within the street system influences street front attractiveness and land value: buildings on streets with high spatial choice value are more likely to experience changes (Törmä *et al.*, 2017). Thirdly, the shape of the plot allows the installation of functions with variable resistance to economic conjuncture: large-scale elements have slower adaptive cycles than smaller ones (Feliciotti *et al.*, 2018; Habraken and Teicher, 1998). Finally, external agents, such as individual decisions or expected new urban developments, have an impact on building lifecycle (Kropf, 2001; Whitehand and Whitehand, 1984). This non-exhaustive list of factors explains why most urban street fronts do not follow a homogeneous plot cycle, as theoretically drawn in Figure 2b. Heterogeneous street fronts may present a mitigation effect through complex continuous adaptive cycles, as shown in Figure 2c. To characterize this complex continuous adaptive cycle, Feliciotti *et al.* (2018) have applied the conceptual framework of adaptive renewal cycles of socio-ecological systems (Gunderson and Holling, 2002) to morphological cycles. In doing so, they defined the urban adaptive cycle as four phases: creation, growth, collapse and reinstitution (Feliciotti

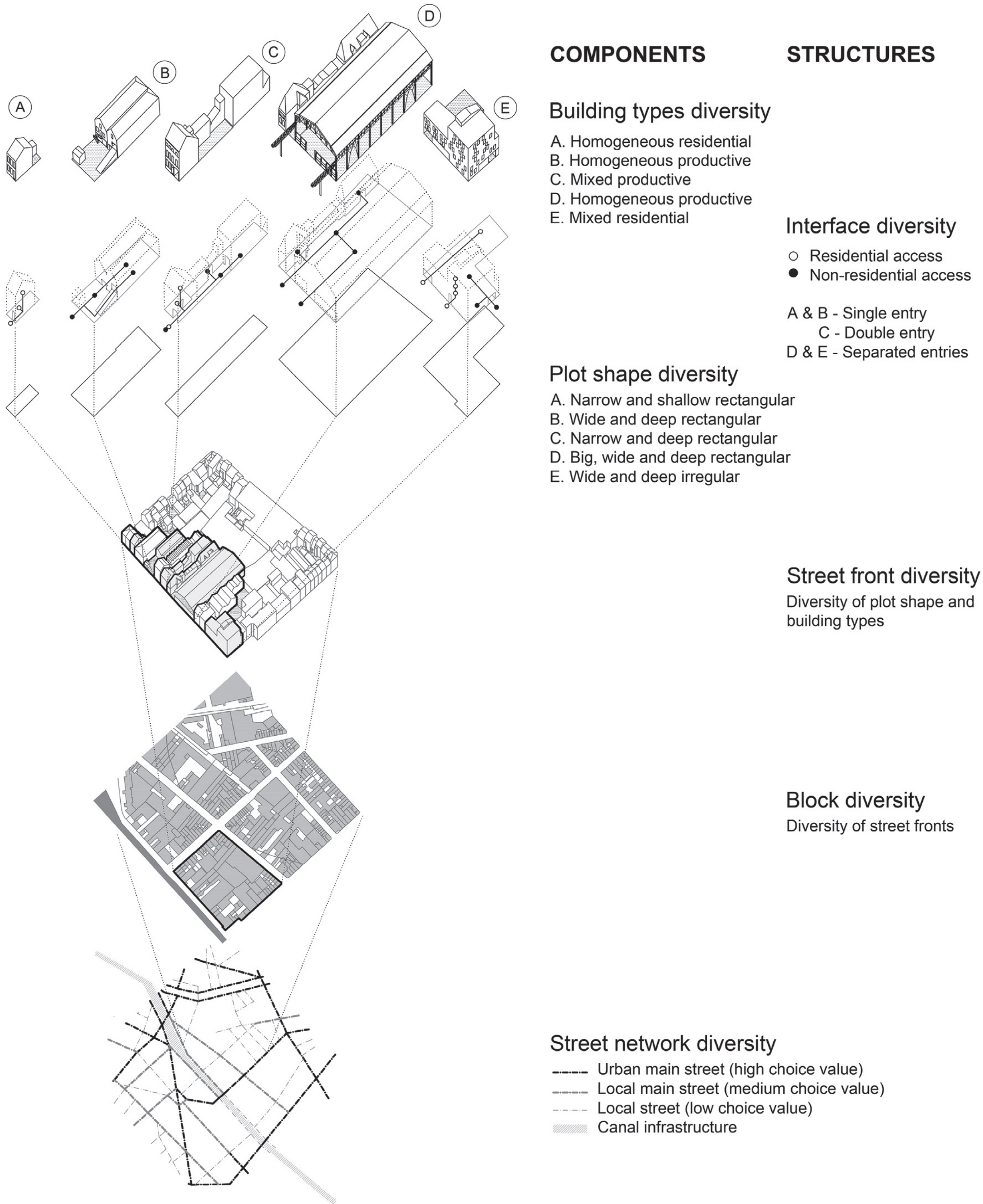

Figure 1. Compositional hierarchy of Brussels heterogeneous urban fabrics with a high level of typo-morphological diversity.

et al., 2018, pp. 3–4) (Figure 2c). This definition will be used here as a methodological framework for the study of heterogeneous urban fabric adaptive cycles. It should be noted that Figure 2 highlights the hypothesis of plot cycle completion based on individual plot evolution. It does not highlight complex and transcalar synergies between morphological components during morphological processes.

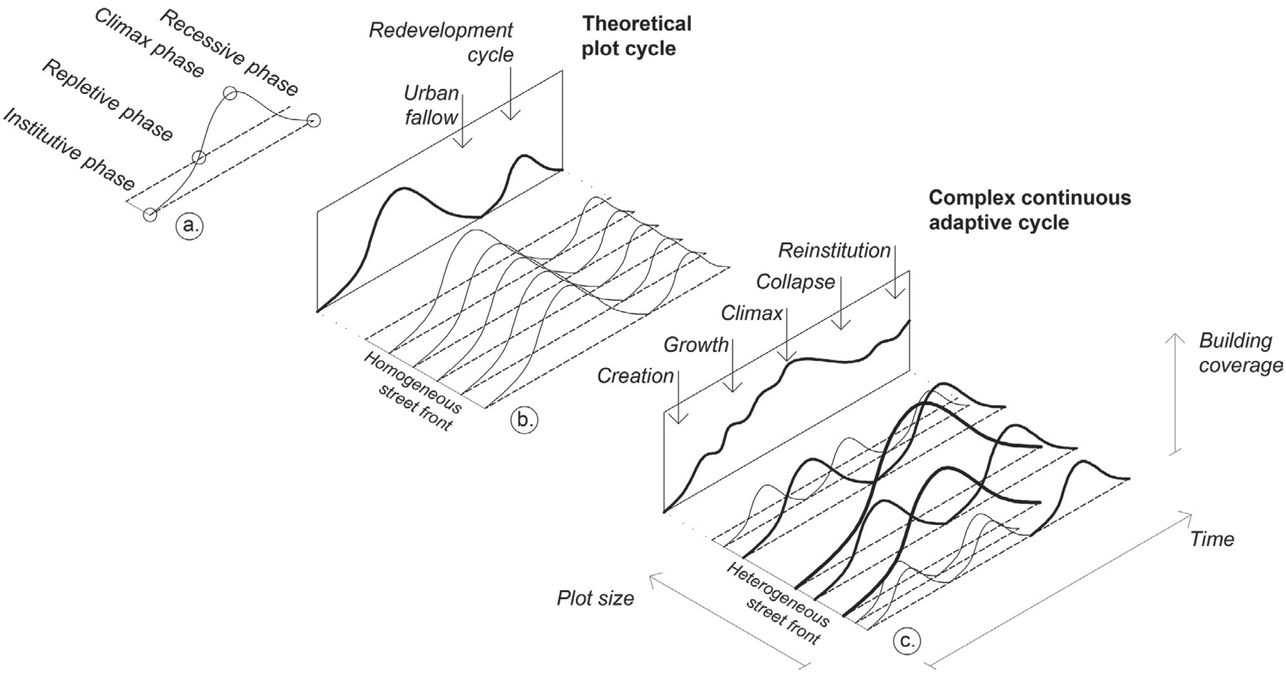

Figure 2. Theoretical comparison between the burgage cycle conceptual framework (a and b) and complex continuous adaptive cycles (c). Adapted from Larkham and Jones (1991, p. 69) and Conzen (1960).

State of the art

Recent typo-morphological investigations on suburban high streets have highlighted the correlation between urban form diversity and urban robustness and adaptability (Carmona, 2015; Clossick, 2017; Griffiths *et al.*, 2008; Törmä *et al.*, 2017; Vaughan, 2015). Nevertheless, these cases present a specific linear condition and a particular historical urban role and attractiveness (Carmona, 2015; Vaughan, 2015), which allow only for a partial understanding of adaptive processes of complex heterogeneous urban fabrics. For instance, the impact of changes in the street system and the role of street corners are not observable. Consequently, this paper aims to determine to what extent TMD is an enabler of urban resilience by guaranteeing urban fabric continuous adaptive capacity. The next section will present an exploration of adaptive processes of the heterogeneous urban fabrics of Brussels through the morphogenesis of three case studies with a high degree of TMD.

Selection of case studies

The selection of case studies followed a cumulative set of criteria extrapolated from the theoretical framework (see Table 1). They are part of a heterogeneous urban fabric presenting a high degree of TMD at street, plot and building levels. They have undergone a complete urban fabric adaptive cycle. The selection is based on urban fabrics that have street fronts, street corners and block units with a variety of spatial combinations of urban fabric components facing similar contextual changes and undergoing change in each component. Nonetheless, one should notice that some relevant selection criteria have been intentionally set aside. First, cases with flat topography have been preferred in order to maximize findings applicable to a great number of potential cases, although topography, ecological networks, and soil properties condition large-scale urban structures and generate many local complexities. Secondly, only changes in the built form are monitored in the analysis. Flexibility, understood as

Table 1. Cumulative set of criteria for case study selection

Condition	**Criterion**
Limited study perimeter	Urban blocks
Four periods of adaptive cycle	Creation: *c.* 1830–1870 Growth: 1870–1930 Collapse: 1930–1995 Reinstitution: from 1995
High typo-morphological diversity	Street network diversity Plot shape diversity Building type diversity
Variety of spatial combinations of similar components	
Change in each component	

the possibility of making new uses of existing buildings without changing them, is not studied because of a lack of precise data over long periods. Understanding the impact of topography and flexibility on adaptive cycles is therefore left for further investigation.

Relevant cases were found in Brussels, Belgium. Particular heterogeneous urban fabrics made up of small and medium productive buildings fully integrated with the surrounding dense urban fabric (De Voghel *et al.*, 2018; Vandermotten, 2014) are found along high streets, around urban productive nodes and in the Senne valley on both sides of the canal (Le Fort, 2019). The selected case studies – Quai de l'Industrie blocks 1 and 2 and Quai des Charbonnages block 3 – are included in a survey of heterogeneous blocks in Brussels (Le Fort, 2019) with a high mix of uses (Bureau bruxellois de planification, 2017) (Figure 3). They are situated inside the Urban Renewal Area (ZRU) and in the Canal Territory, a strategic redevelopment area defined in the Regional Sustainable Development Plan (PRDD). They are involved in a Sustainable Neighbourhood Contract area – Brussels small-scale urban renewal policies – and they are hosting an ERDF urban renewal project expected to be completed by 2022. Figure 4 shows the diversity of street status – in terms of choice value – surrounding the selected case studies. Moreover, selected blocks have at least one street front facing the canal infrastructure. The case studies are therefore paradigmatic heterogeneous urban blocks with a high level of TMD that have undergone complete adaptive cycles.

According to the definition of urban adaptive cycle suggested by Feliciotti *et al*. (2018), the central section of the Canal Territory has experienced four development phases. Originally, the area was a swamp situated in the Senne valley, where the first canalization of the river dried up the area and allowed the development of pastures, mills, some artisanal breweries and brickyards. The creation phase (*c*.1830–70) began with the development of transport infrastructures such as canals and railways (Hanin, 2004; Lacour *et al.*, 1987; Vandermotten, 2014). After the dismantling of the city walls and bastions (1812–33) and the digging of the Brussels-Charleroi canal (1832), industrial companies settled in the former extramural fringe-belt land. The densification of the blocks and the intensification of land use characterized the growth phase which correlated with the increase in the value of industrial lands due to the industrial boom of Belgium and Brussels. A climax point has been recorded around 1930 with the built saturation of the blocks. The modernization of the central section of the canal forced it into a reinforced transit role (Demey, 2008). Between the 1920s and 1940s, the new lock system and

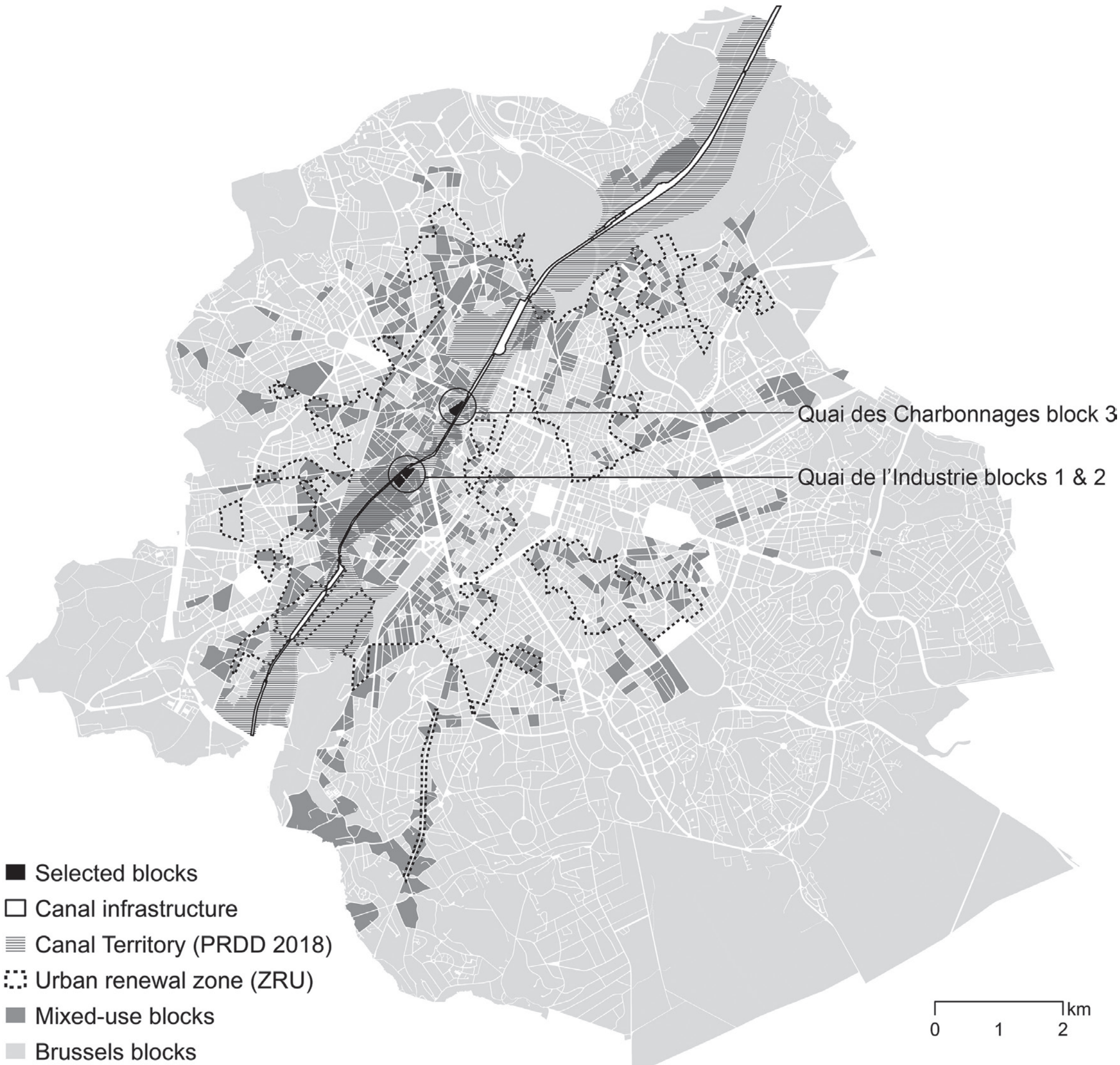

Figure 3. Case study locations along the canal infrastructure inside the Brussels urban renewal area and the Canal Territory. Redrawn from BruGis (2015).

the consolidation of the quays have lowered the water level making the transshipment more difficult (Dubreucq, 1998). This infrastructural and logistical evolution combined with the industrial crisis in Brussels and the decrease in land value in the late 1960s (Vermeulen and Corijn, 2015) influenced the collapse phase from 1930 to 1995, materialized through changes of use, adaptations or replacements of buildings. Finally, the increase in public and private developments reflect a reinstitution phase in the whole area since the early 1990s. Nowadays, in response to economic transition and a demographic boom (De Beule *et al.*, 2012), the implementation of urban regeneration policies lays the foundation for a redevelopment process of the Canal Zone.

Analytical framework

According to Conzen (1960, p. 119), the diversity of features in heterogeneous urban fabrics can be understood by following their morphological processes. Morphogenesis and historical cartography enables identification of the transformations and inertia of an urban fabric (Allain, 2004).

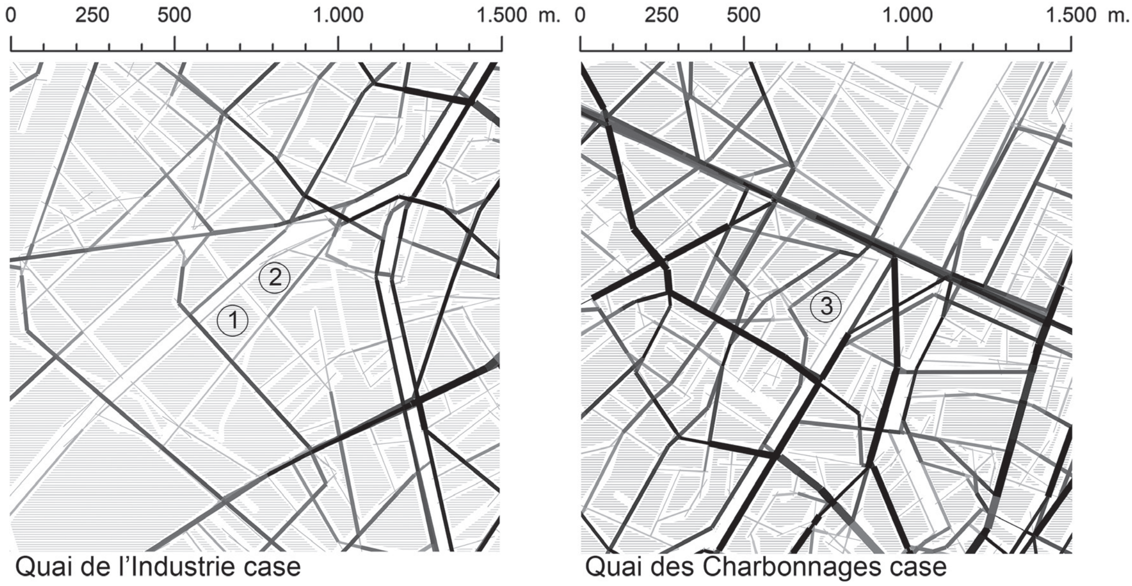

Figure 4. The selected case studies are surrounded by a diversity of street types (choice value, radius 3200 m, equal ranges, greyscale: the darker the higher choice value, the lighter the lower choice value, computed with DepthMapX). Redrawn from UrbIS (BRIC) and Letesson (2018).

The graphical production for morphogenesis is twofold. On the one hand, case studies are disaggregated into a representation of the street system, the plot pattern, the building layout and an axonometric view of the analysed block and its adjacent street fronts. This disaggregated representation is made for each step of the adaptive cycle. Historical maps (Institut cartographique militaire, 1892; Popp, *c*. 1866), cadastral plans (1995 and 2015 versions), aerial photographs (1930, 1995 and 2015), old postcards and urban renewal project files are the basic research and drawing materials. These data are collected from the Royal Library of Belgium, from the Brussels Regional Informatics Centre and from urban redevelopment project stakeholders. Projections towards 2022 are used in order to analyse the complete adaptive cycles of case studies. The resulting morphogenesis matrix allows observation of changes in morphological components and specifically studying synergies between them during a complete adaptive cycle.

On the other hand, quantitative criteria are calculated and drawn on a graph to objectify observations (see Table 2). First, investigations are carried out on the evolution of the street network. The street network diversity is extrapolated from a street network choice value calculation for Brussels (Letesson, 2018) correlated with public space patterns (Marshall, 2005). Secondly, plot pattern evolution is examined with regard to the alterations in the shape of original plots due to division, subdivision or amalgamation processes. The plot size means are calculated for each block and period. The standard deviation of plot size gives an indication of the balance in the distribution of plot sizes within the block: the closer the mean and standard deviation, the more balanced the distribution, which means a limited number of large elements, a medium proportion of medium elements and a high proportion of small elements (Jacobs, 1961; Salat *et al.*, 2014). Thirdly, Building Coverage Ratio (BCR) and Floor Area Ratio (FAR) indicators objectify observed adaptive cycles. The relation between BCR and FAR highlights the difference between a densification without typological change and a typological mutation. The analysis focuses on the

Table 2. Adaptive cycle analytical grid

Component	Criteria	Observations
Street network	Hierarchical pattern	Evolution of street diversity
Plot pattern	Number of plots in block Mean of plot sizes in block	Plot subdivision and/or regrouping
	Standard deviation of plot size	Evolution of plot size/shape diversity
Building types	Building coverage ratio (BCR) Floor area ratio (FAR)	Repletion, saturation, decline Densification, typological change Evolution of building diversity

interrelation between changes in the three morphological components.

Findings

Analysis of blocks 1 and 2

Blocks 1 and 2 (Figure 5) are part of the Heyvaert district. The initial development process concerns medium factories processing raw materials, luxury goods factories, and a series of activities linked to the nearby presence of slaughterhouses. These blocks result from an initial large and regular layout of streets (Figures 6 and 9: street system in 1866). Rue de Liverpool (Figure 5, label 4) is an east-west main urban street connecting districts on both sides of the canal. Quai de l'Industrie and rue Heyvaert (Figure 5, labels 1 and 2) are both parallel local main streets giving access to industrial installations.

From 1866 to 1892, plot subdivisions and built fabric development characterize the growth phase, which followed the creation of a new bridge to the north connecting the studied area to Brussels' ring boulevards and the city centre (Figure 9: street system in 1892). Storage warehouses and workshops for processing raw materials were built along the canal, with a concentration in the northern area, near to the lock. Factories producing finished goods were established along rue Heyvaert. Worker houses were erected along rue de Gosselies, a local street. The construction in 1890 of a new slaughterhouse on the southern part of the extended rue Heyvaert drove the development of related activities in block 1. Consequently, the growth phase featured few plot adaptations but an increase in building coverage due to a strong repletive process within the plots (see Figures 6 & 9: plot pattern and building layout in 1892).

In 1930, at its climax situation, block 1 presented a complex organization of its street fronts optimizing the space available in the block (Figure 6: plot pattern in 1930). The median spaces of the block were covered by wide and deep plots used for industrial activity. Small plots were located on street front extremities, resolving the angle situation with small corner shops. Hybrid mixed productive built configurations were located on narrow and deep plots between the median wide and the small corner plots. The resulting plot pattern answered the need for a balanced built environment mixing factories, warehouses, small workshops, houses and small corner shops.

The collapse phase affected the two blocks in different ways. The northern part of block 2 was strongly affected by the canal realignment (Figure 10: street system and plot pattern in 1995). The transformation of the quayside into an open space instituted the urban fallow of an entire plot series (building layout in 1995). Figure 11 shows the great increase in plot size due to amalgamations and a decrease in both BCR and FAR due to building demolitions. Inversely, except for a few plot adaptations along rue de Liverpool due to the replacement of derelict and obsolete buildings, block

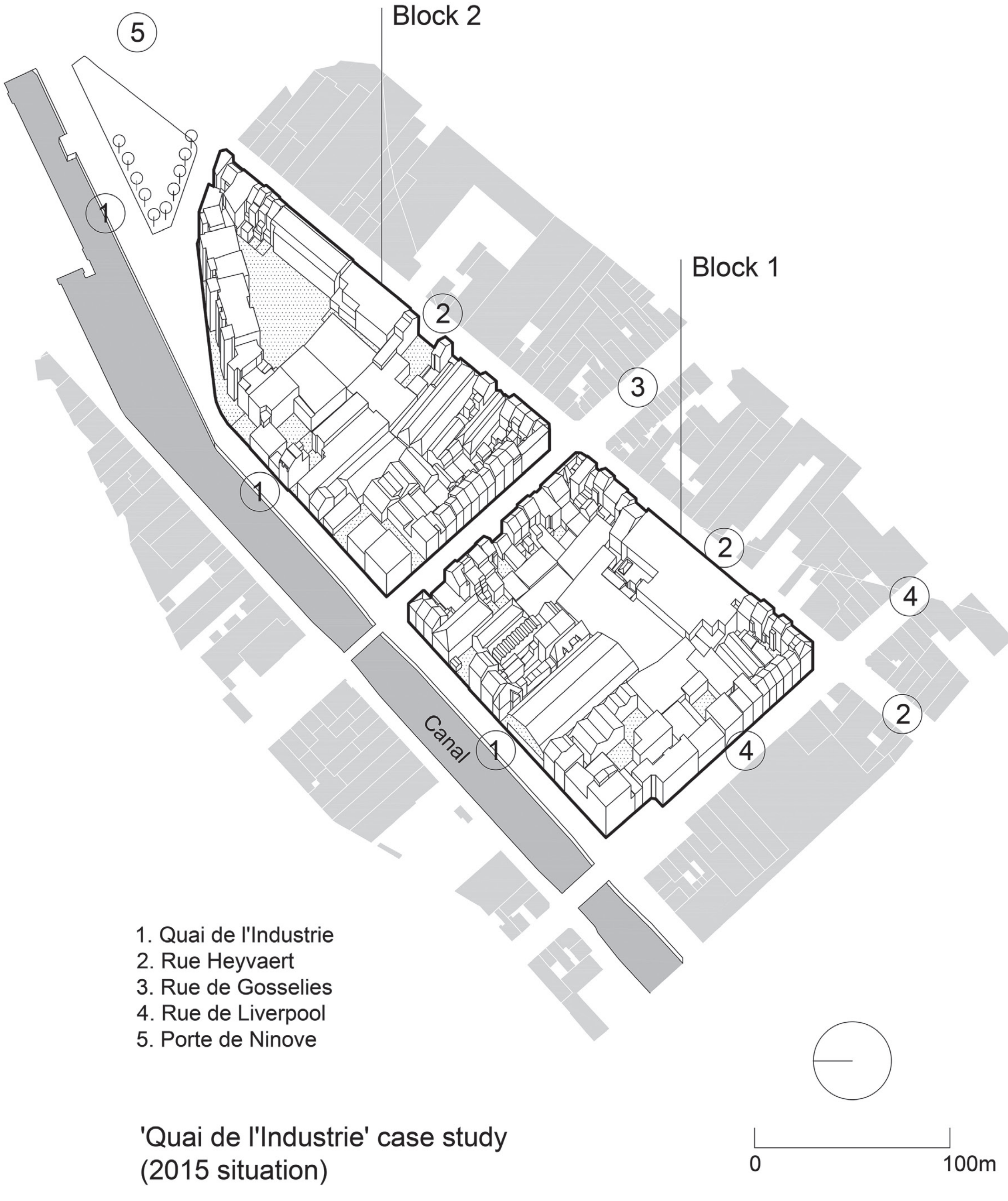

Figure 5. Current composition of blocks 1 and 2.

1 included an economic reconversion without strong typo-morphological changes (Figure 7: plot pattern and building layout in 1995). Indeed, in 1970, new norms in the food sector led to the relocation of a large number of activities related to slaughtering and the meat trade. Second-hand car import-export companies quickly took up the large and cheap industrial spaces to store vehicles (Rosenfeld, 2015).

As part of this urban renewal area, blocks 1 and 2 and adjacent ones have been subject to urban revitalisation projects since the 2000s. The reinstitution phase began by downgrading

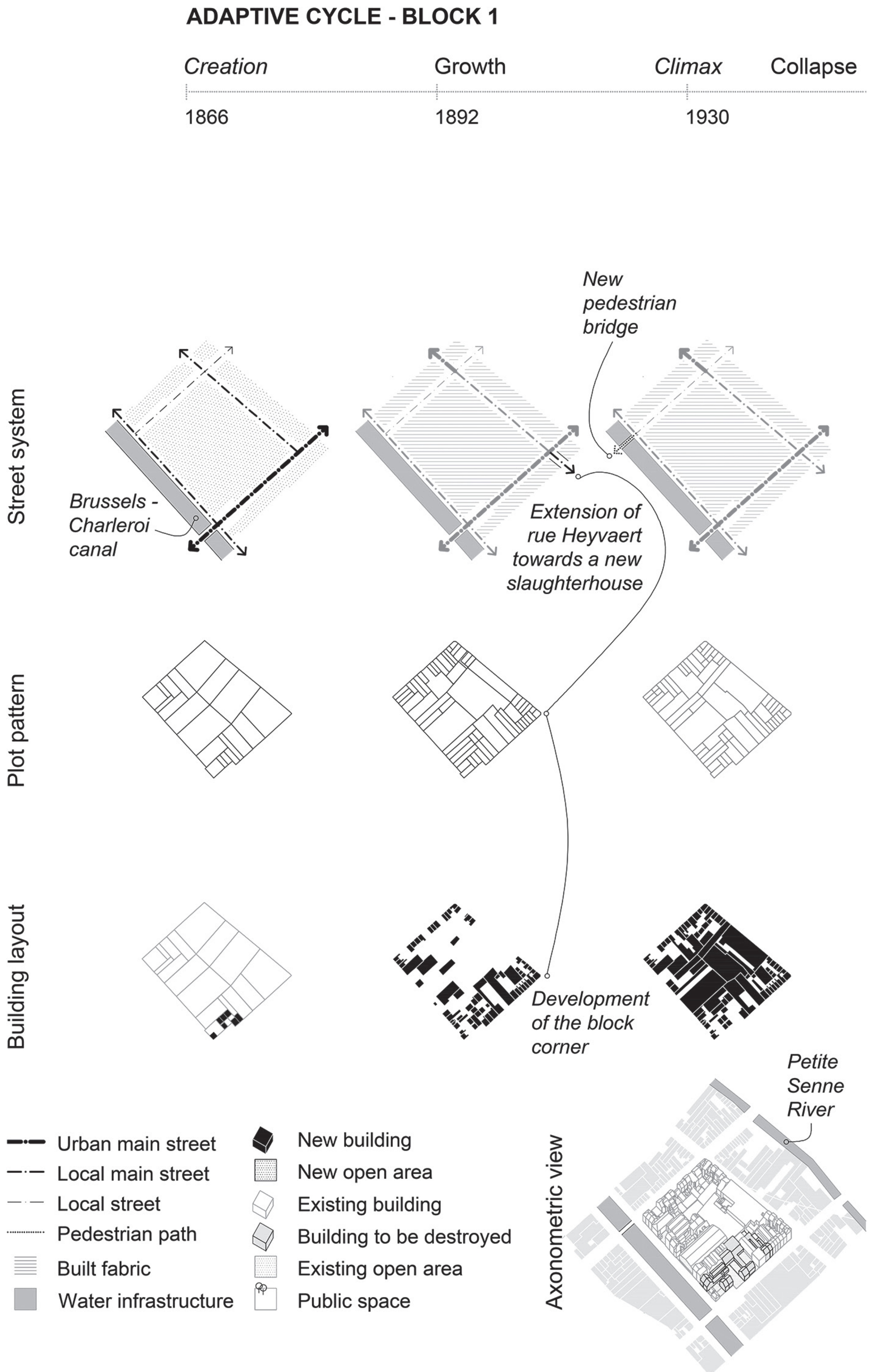

Figure 6. Adaptive cycle analysis (from creation phase to climax) of block 1.

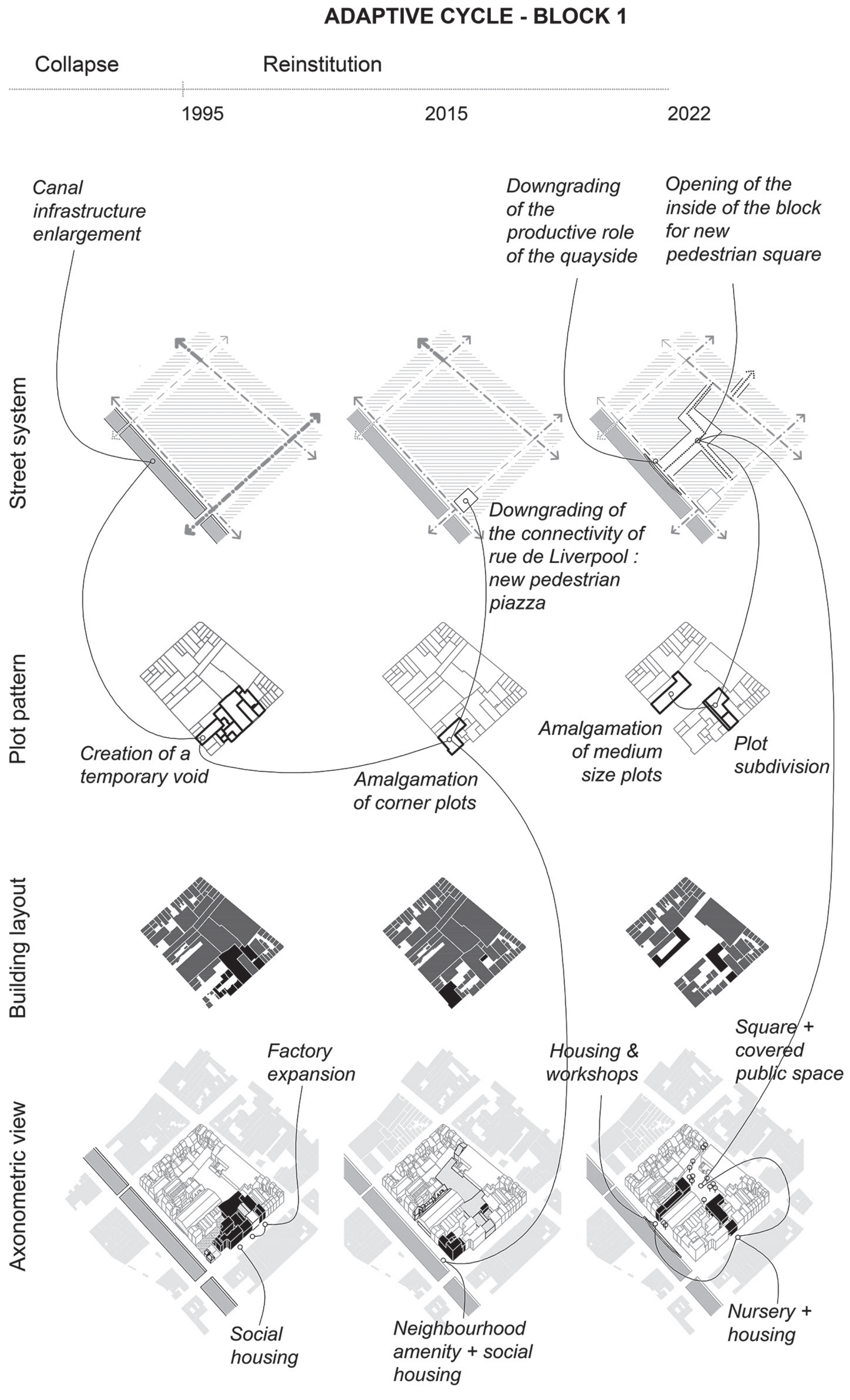

Figure 7. Adaptive cycle analysis (from collapse phase to reinstitution) of block 1.

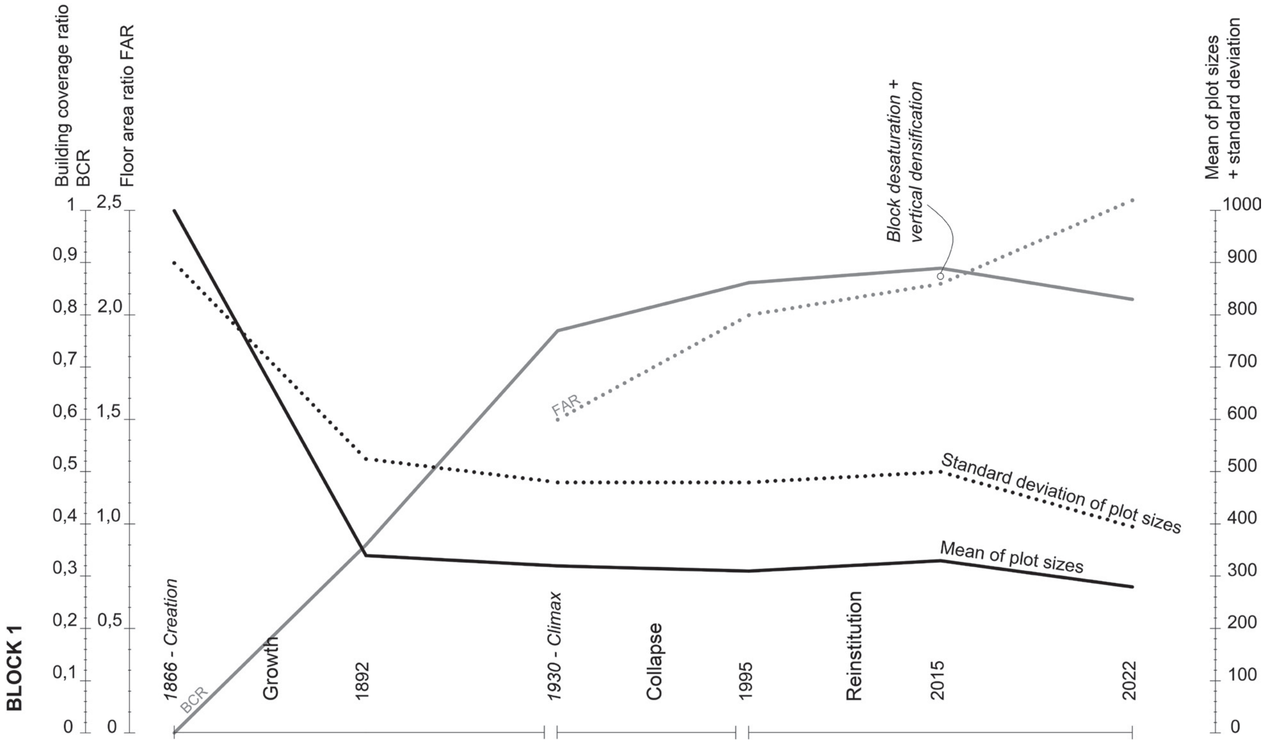

Figure 8. Adaptive cycle measures of block 1.

the hierarchical role of rue de Liverpool and quai de l'Industrie (Figures 7 and 10: street system in 2015). This street system adaptation led to plot amalgamations and densification by typological mutation (increase in FAR, see Figures 8 and 11) in front of the refurbished urban spaces. This process decreased the balance of plot size distribution, especially in block 2 which as a result had few very large plots, many small ones, and fewer medium ones (Figure 11: plot pattern in 1995).

The decline in second-hand car exports combined with the intensification of urban redevelopment projects is currently a sign of a structural renewal of the district followed by a socio-economic evolution and an increase in land value. Urban projects expected by 2022 will change the overall morphological structure of block 1: three large median plots will become a pedestrian public space spanning the entire block (Figure 7: street system by 2022). This augmentative development will enable block desaturation and intensification by plot amalgamation and typological mutation for new specialized frontages within the block (Figure 7: axonometric view by 2022). A similar renewal process is projected in neighbouring block 2 and will be correlated with the readjustment of Porte de Ninove's street node into a park (Figure 10: street system by 2022). These projects will change the street system for motorized vehicles back to a loop configuration. This new street system may cause a decrease in the choice value of rue Heyvaert and the quayside, given the risk of a loss of attractiveness for enterprises and an increasing pressure for residential developments.

Analysis of block 3

Block 3 (Figure 12) is part of the historical Molenbeek neighbourhood. Its particular triangular shape was influenced by the former presence of an old bastion of the medieval city wall. During the creation phase and until 1944, the Petite Senne River crossed the block parallel to the canal (Figure 13: street system in 1866, 1892 and 1930) and

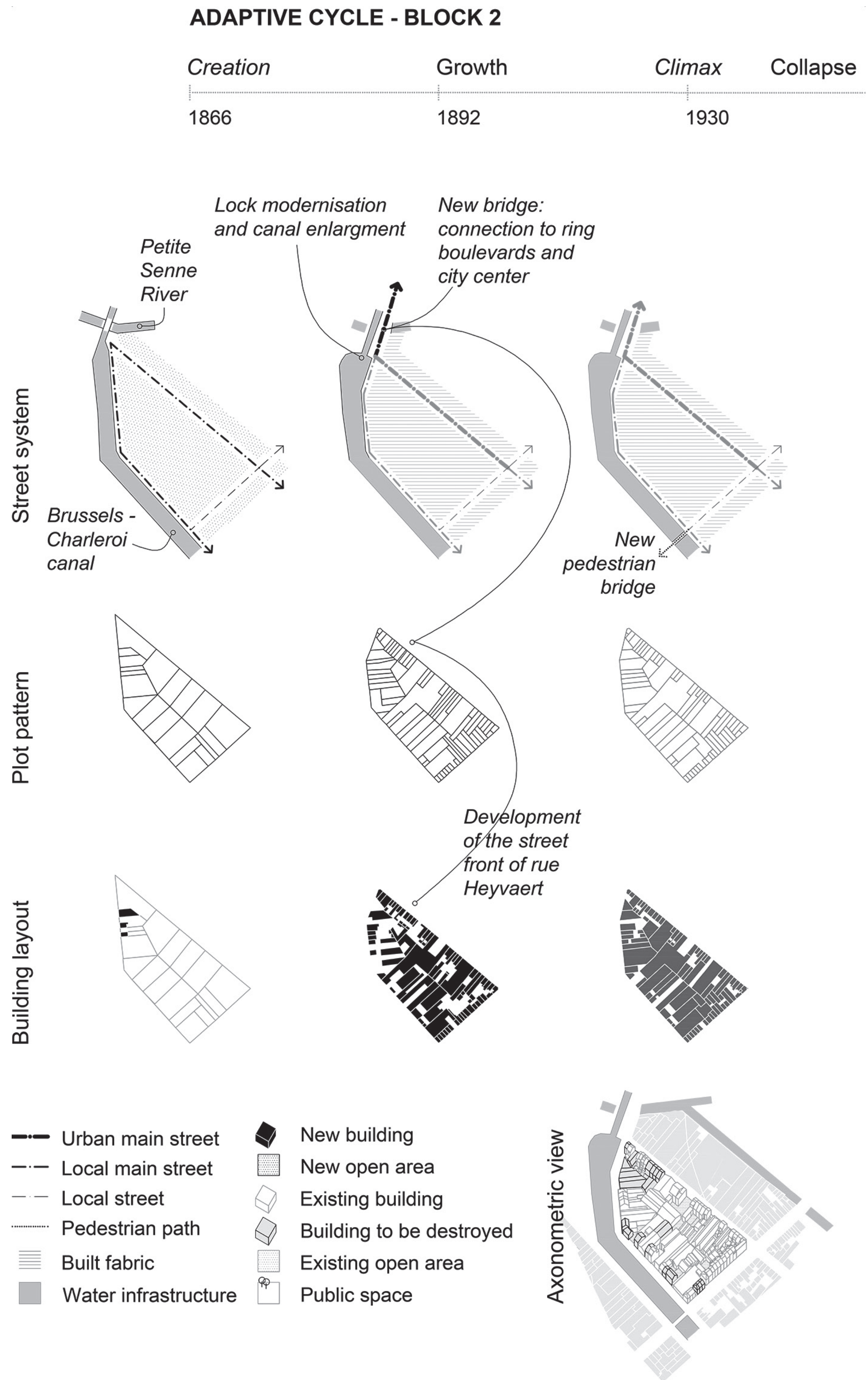

Figure 9. Adaptive cycle analysis (from creation phase to climax) of block 2.

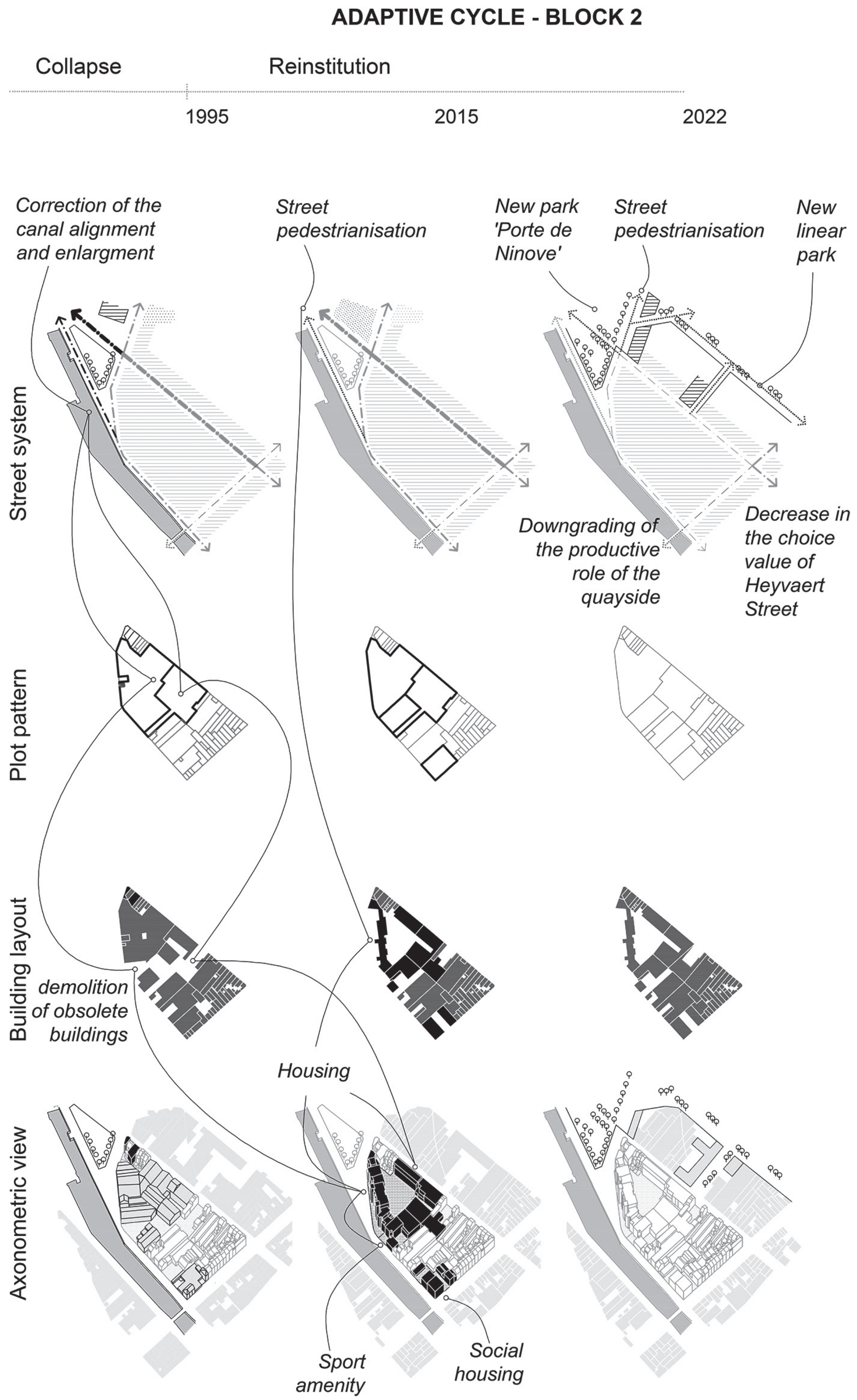

Figure 10. Adaptive cycle analysis (from collapse phase to reinstitution) of block 2.

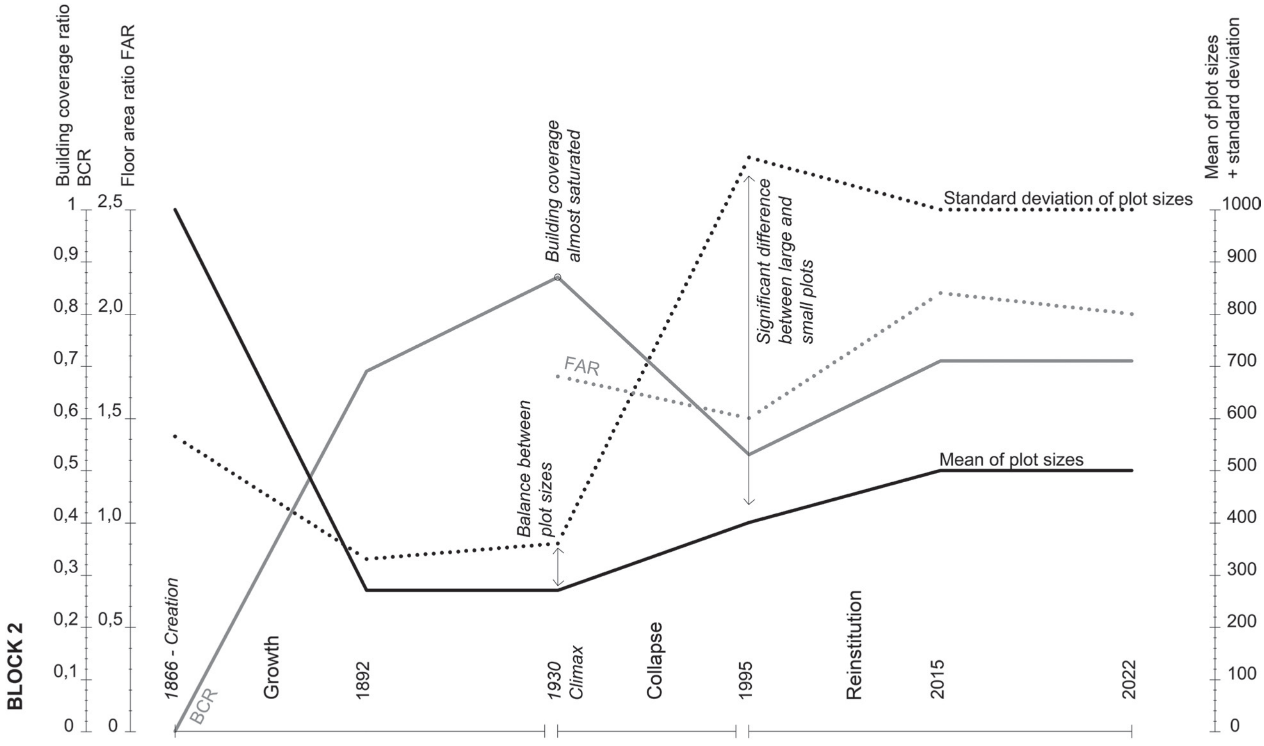

Figure 11. Adaptive cycle measures of block 2.

played a role of technical axis for the evacuation of industrial waste and the cooling of foundries.

Block 3 presented an institutive regular plot pattern (Figure 13: plot pattern in 1866) composed of wide and deep plots facing the canal along quai des Charbonnages, the main urban axis and canal towpath (Dubreucq, 1998). The oldest irregular northern part of the block disappeared during the growth phase owing to the breakthrough of boulevard Léopold II and place Sainctelette (street system in 1892). In parallel, the block experienced a great densification owing to plot subdivision and repletive processes coupled with the street network augmentation (situation in 1892). Thereafter, plot and building adaptations remained stable until 1930.

A reverse process of plot amalgamations (increasing in the mean of plot sizes in Figure 15) characterized the collapse phase, mainly on the central and southern part of the block (Figure 14: plot pattern in 1995). The canal enlargement and the vaulting (culverting and covering) of the Petite Senne River at the end of the Second World War initiated the gradual disappearance of productive buildings, which were replaced in the early 1970s by denser typologies linked to the development of tertiary activity and wholesalers (Figure 14: axonometric view in 1995).

The reinstitution phase began with the creation of Petite Senne Park within the block, coupled with downgrading quai des Charbonnages from its productive role to being a local street (Figure 14: street system in 2015). This street system evolution was followed by plot amalgamation with typological mutation on strategic double-frontage situations along the quayside (see new housing in axonometric view). However, the adaptation of old warehouses into a small centre for SMEs reflected the conservation of rue des Ateliers as a productive local main street with very few morphological changes.

A new mixed urban landmark and a new sport facility are expected by 2022 (Figure 14: 2022 axonometric view). This significant densification with typological mutation (Figure 15: FAR increase between 2015

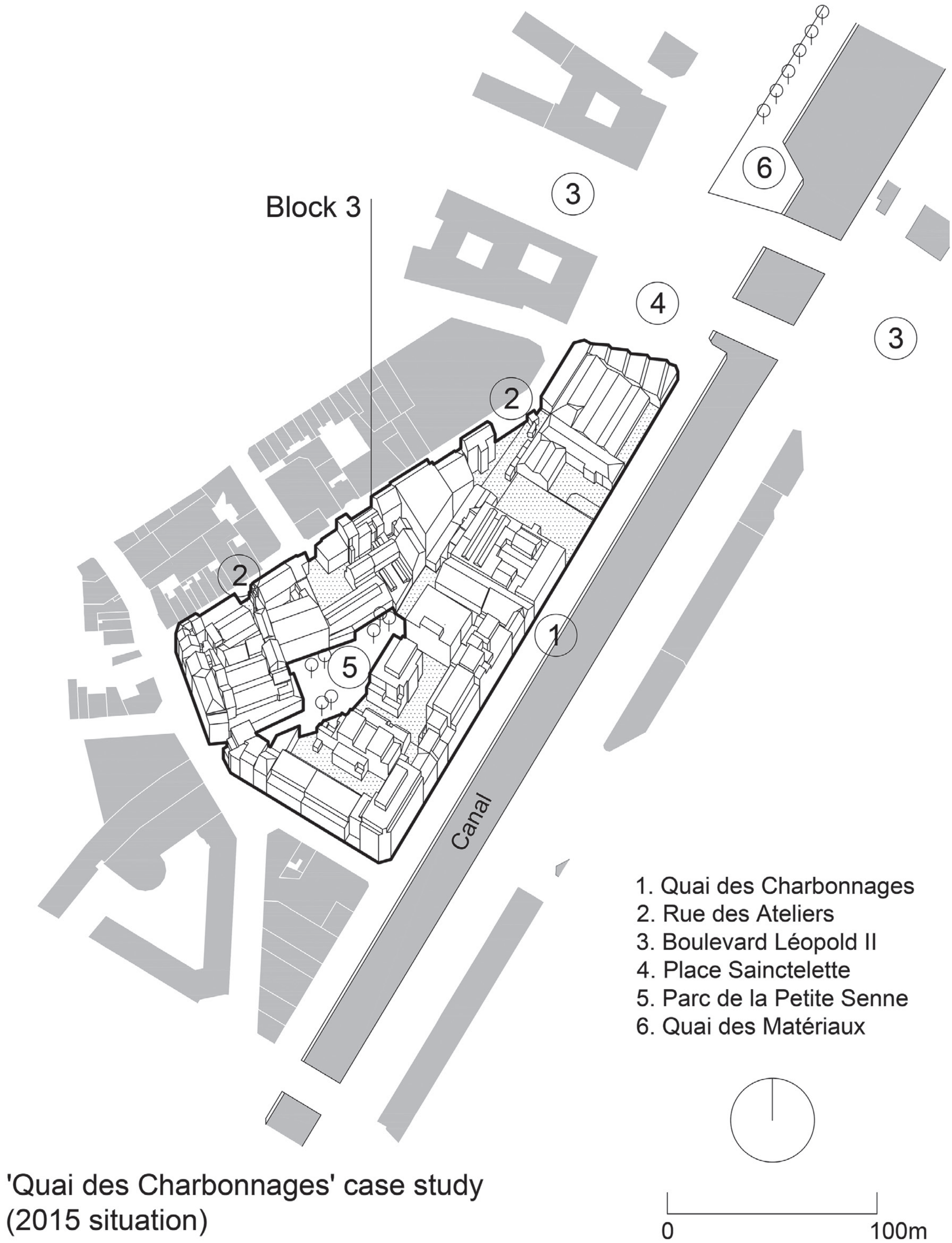

Figure 12. Current composition of block 3.

and 2022) will accompany street network augmentation (expected linear Petite Senne Park completion) and the creation of a new large open space in the north: Quai des Matériaux Park (Figure 14: street system by 2022).

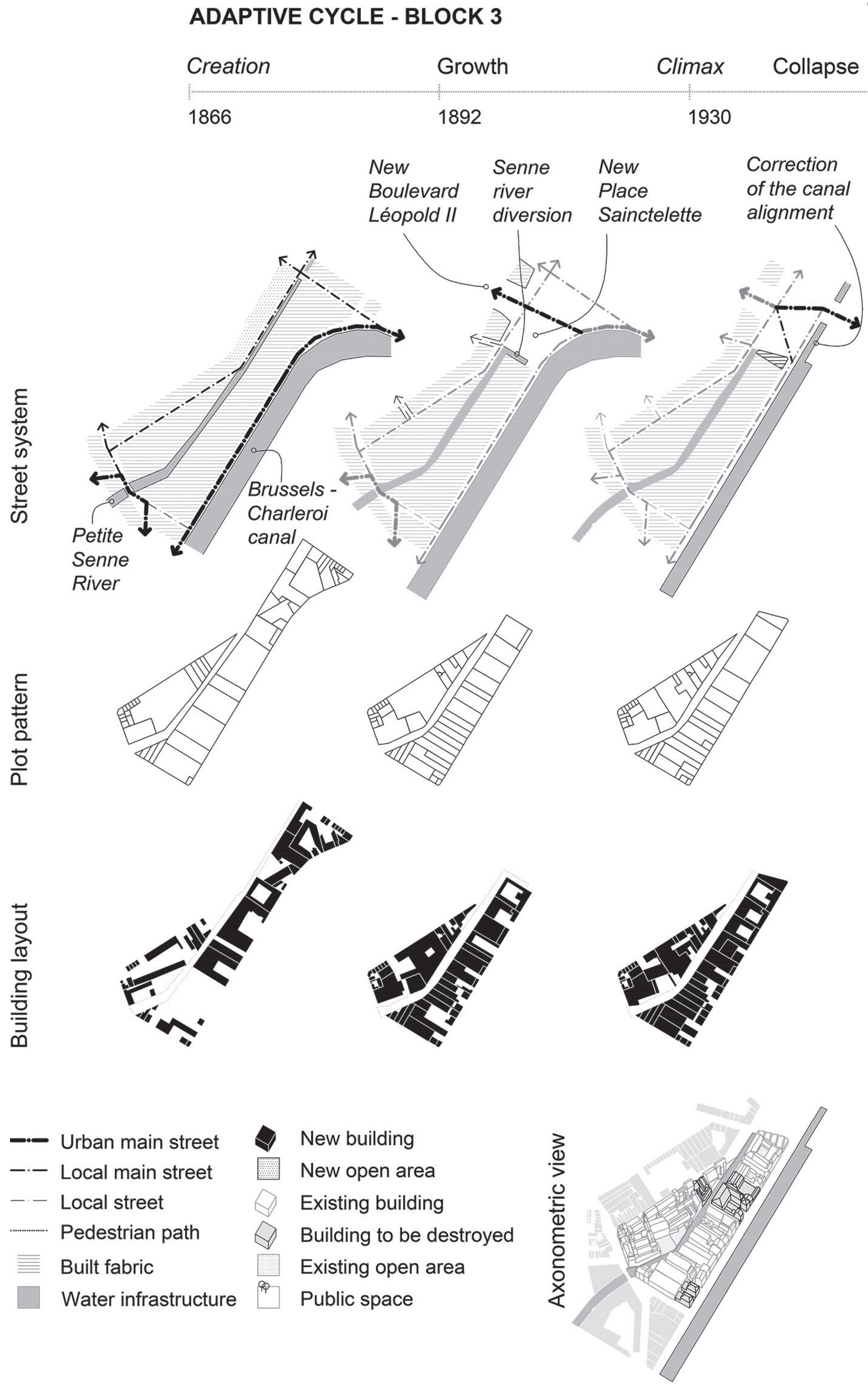

Figure 13. Adaptive cycle analysis (from creation phase to climax) of block 3.

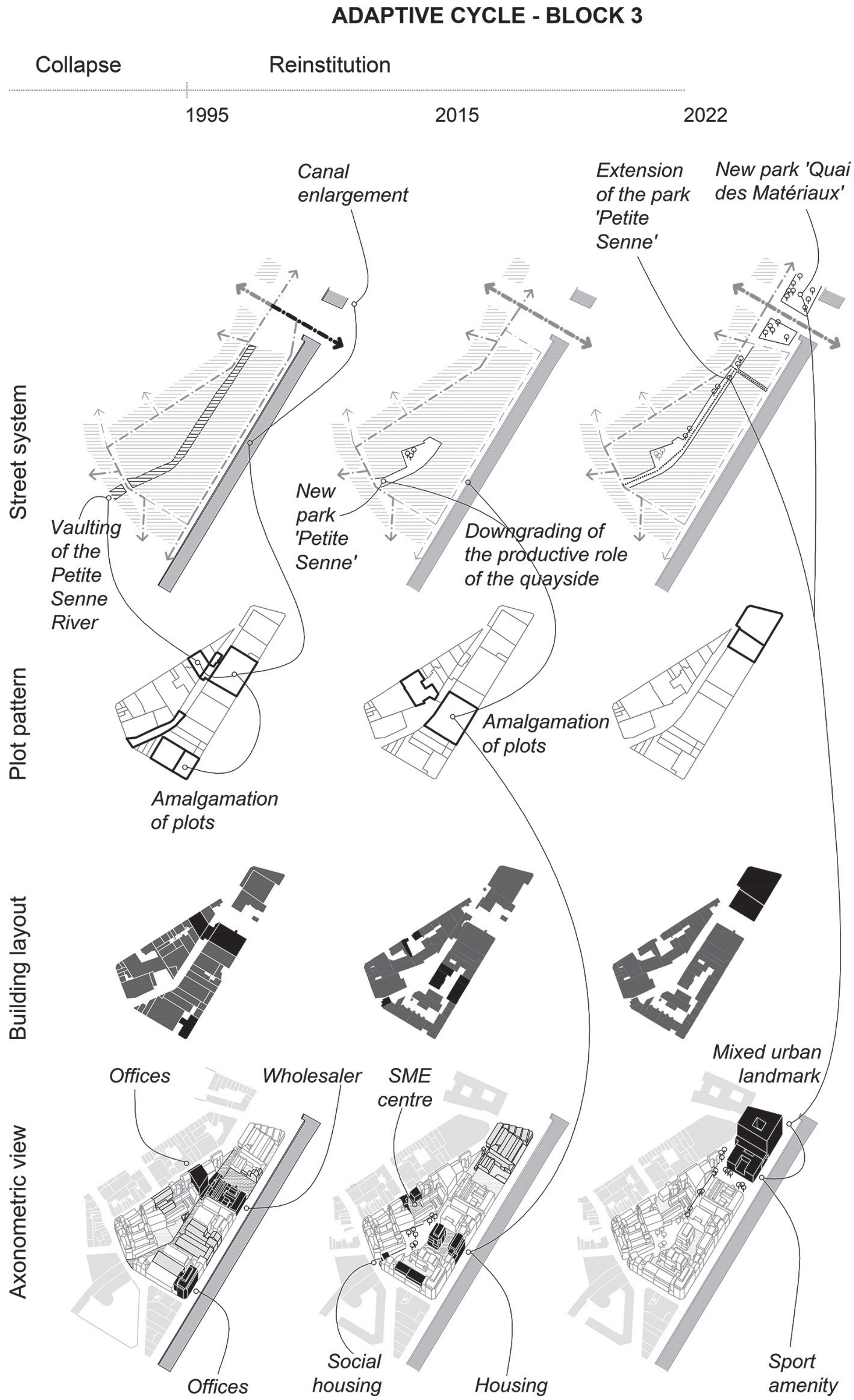

Figure 14. Adaptive cycle analysis (from collapse phase to reinstitution) of block 3.

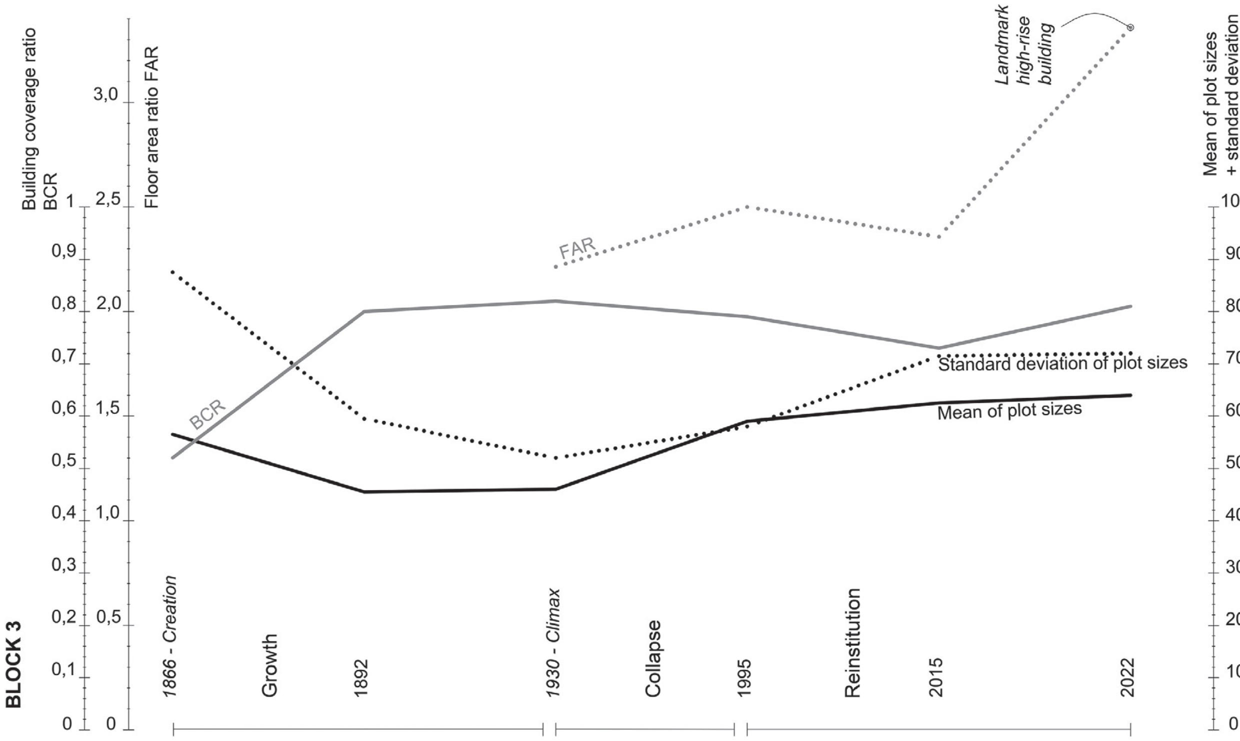

Figure 15. Adaptive cycle measures of block 3.

Discussion of comparative analysis

As assumed in the conclusion of the theoretical framework section of this paper, the choice of case studies with interrelated logics of street fronts, street corners and block units allows for a complete, critical understanding of adaptive processes. Further research should focus on smaller and larger scale factors.

According to the adaptive cycle model (Holling *et al*., 2002), resilience is a property activated at some point in the life cycle of a system. Consequently, resilience is regarded as a positive value during periods of urban collapse and reinstitution (Chelleri, 2012; Hassler and Kohler, 2014; Marcus and Colding, 2014). We thus have focussed our analysis on those phases.

In response to the general hypothesis, the case studies present robustness through differentiated adaptability at the component scale. Indeed, on the one hand, the analysed heterogeneous blocks present no complete collapse or rebuilding, but rather changes at component scale. On the other hand, we do not observe adaptability of all components at all times, but rather differentiated resistance, collapse and adaptations at component scale.

Figure 16 represents a synthetic comparison of the three morphogeneses shown in the previous section. It highlights four recurrent typo-morphological processes, which are particularly visible in plot pattern evolutions (Figure 16, labels 1–4).

Label 1 shows that the erection of industrial buildings on large plots on the central part of street fronts were the dominant principle of development during the growth phase. This process occurred mainly on local main streets: retail activity took place along urban main streets through taking advantage of their high choice value, and housing and craft activities took place along local streets.

These large median plots show a slower adaptive cycle but a more radical mutation process as compared to smaller plots, as indicated on Figure 16 by label 2. During the reinstitution phase, the need for more green open spaces drove their conversion into public spaces. This deep transformative

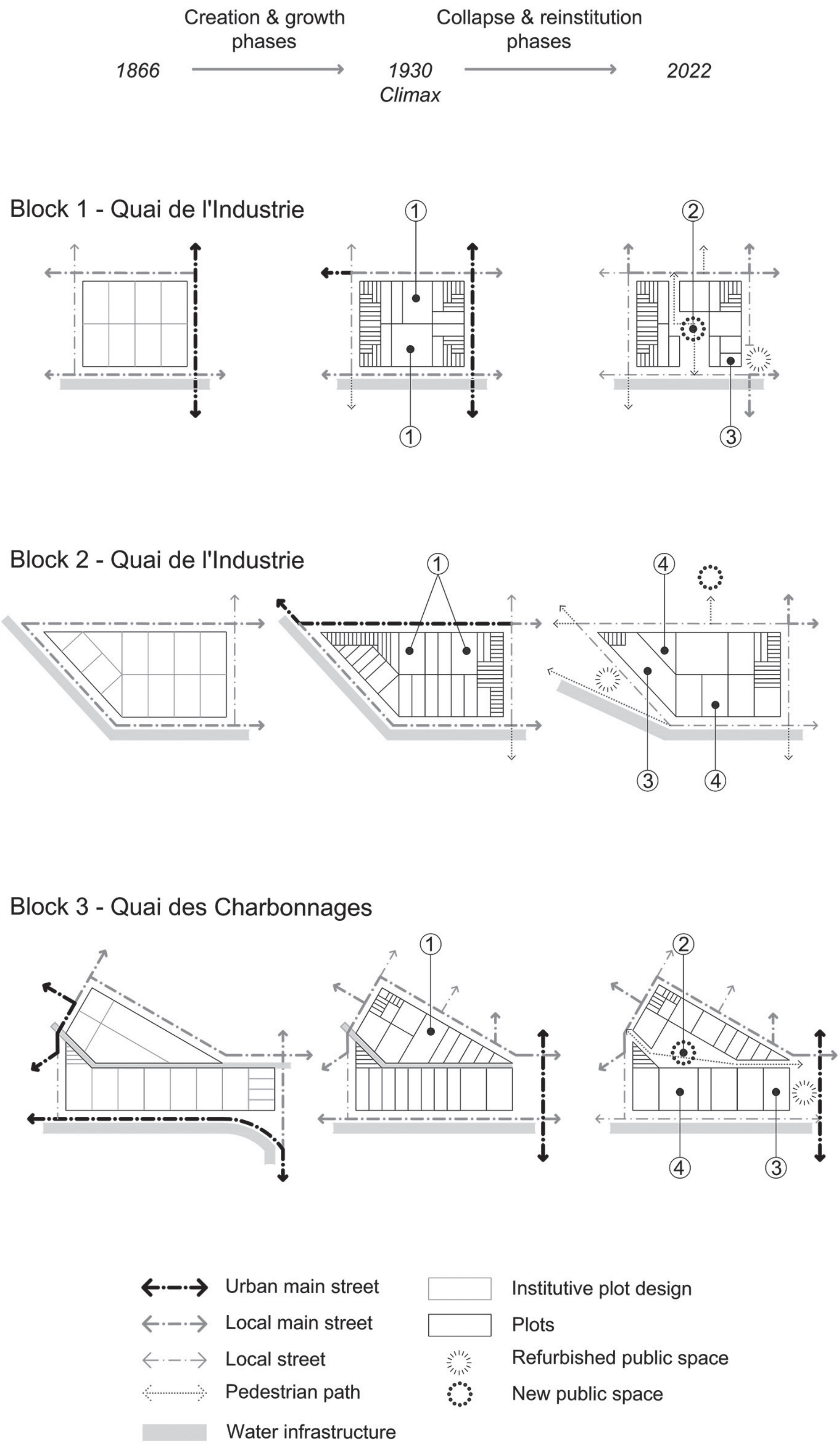

Figure 16. Comparative synthesis of case studies adaptive cycles. Four recurrent typo-morphological processes are highlighted (see text for discussion).

process – visible in blocks 1 and 3 and in the urban fabric surrounding block 2 – reflects the actual socio-economic shift of the area: from a productive district, which needs large blocks, into a more residential one, which needs a more permeable street network.

Consequently, the dominant principle highlighted on label 1 was reversed during the reinstitution phase. Label 3 shows that the current main plot pattern modifications and typological mutations occur on corners facing (refurbished) public spaces after the downgrading of adjacent street hierarchical position. Corners are simultaneously strategic and fragile locations.

Finally, label 4 presents the loss of hybrid plot/building type due to plot amalgamation in order to replace mixed productive buildings with denser residential typologies. This process happens after the downgrading of urban and local main streets into local ones. This process, particularly visible with block 2, has the effect of reducing the balance between plot sizes in favour of a division between large and small plots. Today, residential waterfront operations accentuate this trend.

All these morphological processes are conditioned mainly by the properties of the street network. During the institution phase, the great diversity of street status, lengths and profiles fostered a great diversity of plots and building types, varying from big to small and including medium hybrids. During the reinstitution phase, the decrease in the street network diversity was followed by an equivalent decrease in plot diversity, with the disappearance of large plots and the merging of medium and small corner plots. This current 'residentialization' of street profiles and the decrease in TMD indicates that TMD is not self-regenerating.

Conclusion

Urban form is not a living object. Humans are the principal agents of morphological change (Kropf, 2001; Whitehand and Whitehand, 1984). However, because heterogeneous urban fabrics host several socio-ecosystems simultaneously facing different stages of growth, crisis or reorganisation, they foster a 'differentiated resistance' allowing for a high continuous adaptive capacity.

The analysis of heterogeneous urban fabrics in Brussels brings new knowledge on the relation between typo-morphological properties of the urban fabric and its adaptability to contextual changes. First, the analysis of multiscalar and iterative correlations between urban form components highlights the role of street network diversity as main driver – generator and protector – of the TMD of blocks. Secondly, the analysis of the case studies shows correlations between the change processes of streets, plot patterns and building types. As a result, street hierarchy evolution, and by extension street design, is a key 'activator' of TMD transformations.

More fundamentally, the study highlights the need to acknowledge the role of TMD in urban resilience strategies. Indeed, in the Brussels context, we observe a current trend of subdivision of heterogeneous blocks, which seems to go along with a reduction in the diversity of plot patterns and building types. Moreover, a general trend towards homogenization of street status and profiles (generalization of local street types), plot sizes (large ones) and building types (apartment blocks with low flexibility) leads to a decrease in resilience of heterogeneous urban fabrics. Consequently, if typo-morphological diversity is a resilient common resource to be protected and regenerated, it is crucial to define measures, indicators and urban policies to overcome the current lack of urban planning tools adapted to this challenge.

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