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Long-term management of building stocks

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Abstract

The built environment is composed of buildings, infrastructures and cultural landscapes (stocks). These man-made artefacts constitute a complex capital (natural, man-made, human, social and cultural) and its evolution is a crucial parameter in sustainable development. Their composition and dynamics can be modelled as flows or as capitals
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In this article

dynamique peuvent être modélisées sous la forme de flux ou de capitaux ou d'une combinaison des deux. L'article donne des exemples de la modélisation du comportement à long terme de différents types de stocks de bâtiments puis analyse et examine leur comportement. Il présente un cadre d'analyse d'économie de ressource et compare des stratégies pour de deux types différents de stocks de bâtiments, à savoir un stock ancien/statique et un stock nouveau/en extension. L'article examine ensuite l'importance des régimes institutionnels pour la gestion à long terme de stocks de bâtiments ainsi que leurs rapports avec l'évolution démographique et les plans de financement de la retraite. Les aspects institutionnels dans le long terme doivent être pris en compte pour éviter les pertes dramatiques de capitaux économiques, sociaux et culturels dans les décennies à venir.

Mots clés: gestion des actifs, stocks de bâtiments, remise en état, rénovation, économie de ressources, développement durable

Keywords: asset management building stock refurbishment renovation resource economy sustainable development

Importance of the building and infrastructure stocks for sustainable development

The built environment, i.e. the production, operation, maintenance and disposal of
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Following the Brundtland definition and consecutive operation-oriented frameworks like Agenda 21, a whole series of assessment methods and tools have been developed and are used today by local authorities, planners, contractors and manufacturers. These methods and tools lead in general to more appropriate environmental solutions than the business-as-usual approach, they relate, however, mainly to individual buildings or sectoral problem fields (e.g. transport, green spaces). Their basic shortcoming is the lack of a clear conceptual framework and common physical basis.

The relation of the built environment as man-made capital to natural capital has two aspects: extracting resources from nature and reintroducing emissions into nature. All enlargement of the built environment is by definition a reduction of nature within common planetary system limits. All building activity is reducing natural capital in one way or another. This flow-based approach is therefore generally related to ‘strong’ definitions of sustainability, tending to postulate priority of constant natural capital (Daly, 1992). Theoretically, no substitution of natural capital through other forms of capital is admitted in this definition. Extending the definition of sustainability to other aspects, i.e. to other forms of capital (economic, social, human, cultural), has lead to the formulation of a ‘general constant capital rule’: a sustainable society would improve its global wealth (available for the future generations) and in this process substitutions of different forms of capital are necessary and possible. (Pearce and Warford, 1993). For example, there is no principal objection to the substitution of economic capital through human capital (investment in education and research). The main discussion is in how far natural capital can be substituted by other forms of capital, and whether at the limit, a society without nature is possible. This ‘weak’ definition of sustainability, which
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The impact of the man-made environment on nature has been considered in the studies made after the first energy crisis of 1973 as nearly exclusively energy related (both as non-renewable resource consumptions and as emissions into nature). The material aspect in the form of embodied energy and waste came up next, through complete mass flow analysis (MFA) (Bartelmus et al., 2001) and life cycle analysis (LCA) (ISO, 1997), related to macroeconomic data (Input–Output Analysis) (Kohler et al., 1999). Even at present the dominant view of politics, administration and practice is that the environmental problem can be solved through standards and new ('innovative') technologies developed for new construction. In the industrialized European countries with large and old building and infrastructure stocks, the research interest shifted already ten years ago to the understanding of the composition and the dynamic behaviour of the stocks, i.e. to operation, maintenance, refurbishment and disposal problems. The flow-oriented approaches, based on system-ecological and thermodynamic models proved to be very efficient, above all through the superposition of mass flows, energy flows, financial flows and information flows in integrated Life Cycle Analysis (Kohler and Lützkendorf, 2002). Using life cycle product modelling techniques, it was possible to make these approaches scaleable from particular objects to urban fragments and national stocks and link them to Life Cycle inventory data.

Integrated modelling (mass, energy, costs) of the German building stock

The evolution of the building demand in Germany has generally been estimated on the narrow basis of trend analysis of construction activity (building permits for new construction and for refurbishment). Only in specific situations like the description of
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approach. The top-down approach uses general macro economic data (input–output tables) and sometimes more detailed industry production data. The bottom-up approach is based on the division of the building stock into buildings, elements, materials, etc. that are linked to detailed (up- and downstream) process analysis. An upper limit of the flows is given by the top-down approach, a lower limit by the bottom-up approach which contains indications where and when the flows appeared.

- Estimation of the future development of these flows that is based on a dynamic model of the ageing and the management of the building stock. This task is complicated due to the longevity of buildings and parts of buildings. Estimates of current input and output cannot be used to predict the future inputs and outputs.
- Systematic mapping of raw materials (process chains), building elements and auxiliary materials, enables the tracking of materials and the understanding of detailed (end-point) environmental impacts. The toxicological effect of particular emissions and the dissipation of problematic materials through deposit, recycling and reuse can be analysed.

This study encompassed all buildings (housing and non-housing) existing in Germany, which proved to be very difficult to establish. Before the study there were no estimations on how many buildings existed in Germany and how large the total gross surface of the stock was (Figure 1). This was particularly problematic for the non-housing stock where better data have been established only recently (Hassler and Kohler, 2004).

Figure 1 Model of the German building stock (Kohler et al., 1999). Half of the stock
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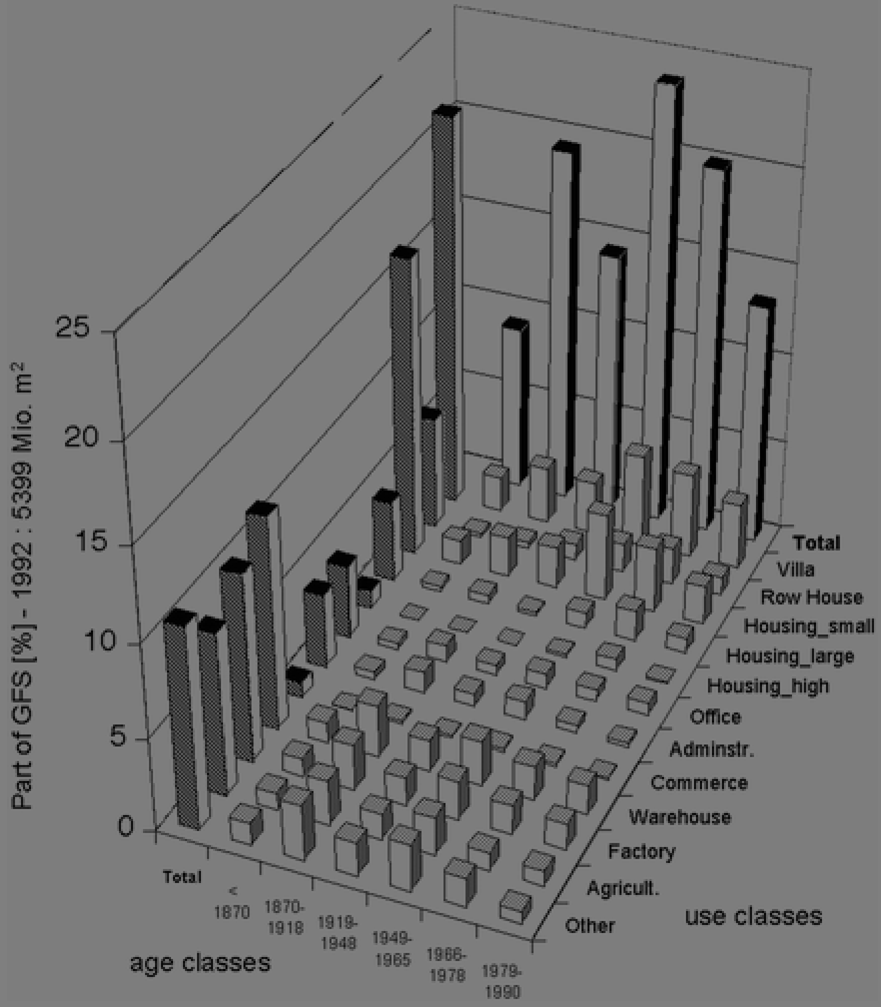

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To establish mass flows buildings are divided along a cost breakdown structure into six element groups and about 50 elements. For each element there are new construction, operation, maintenance, refurbishment and disposal elements with their specifications. All material and process specifications are mapped to approximately 300 Life Cycle Inventories. For each age-use class the interval between refurbishments (average
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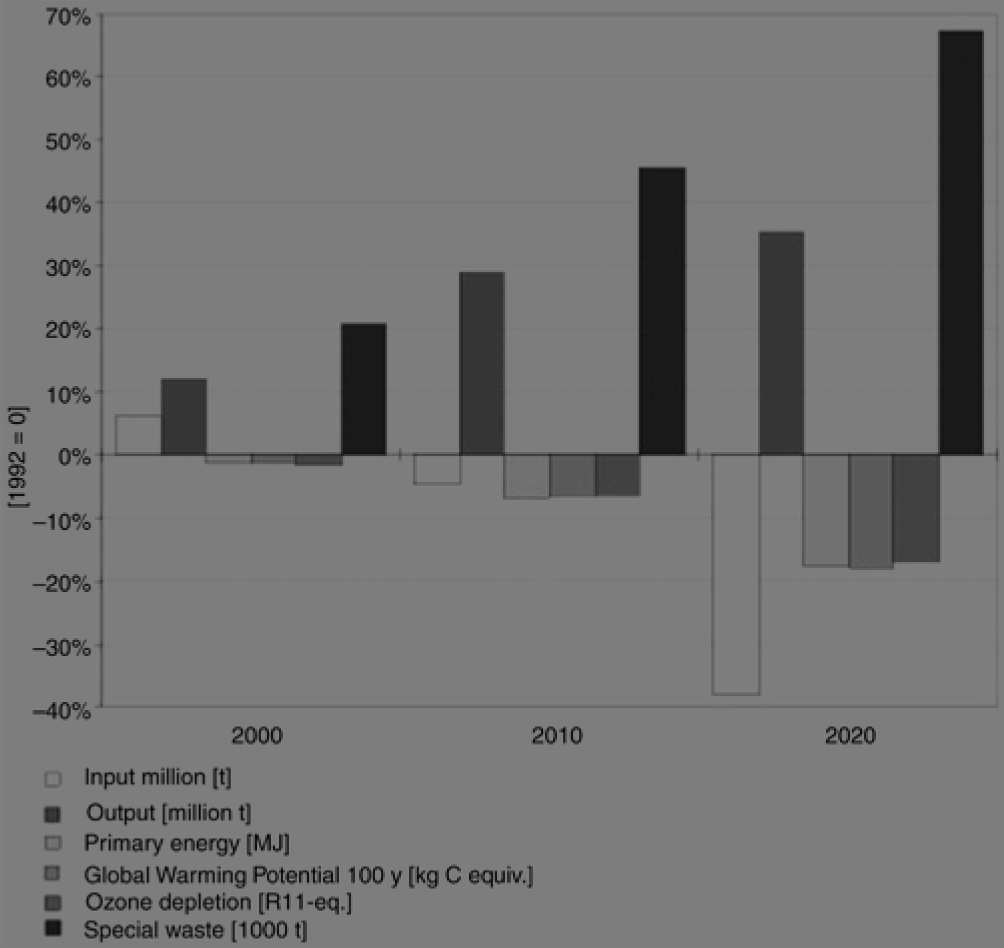
waste, and in particular special waste, increases (Figure 2). The study of the mass flows of auxiliary materials shows a tendency of spreading problematic materials throughout the stock; if no measures are taken, this undesired effect could be amplified through recycling.

Figure 2 Evolution of the mass flows and impacts of the German building stock – the trend scenario. Change with respect to the level of 1992 (Kohler et al., 1999)



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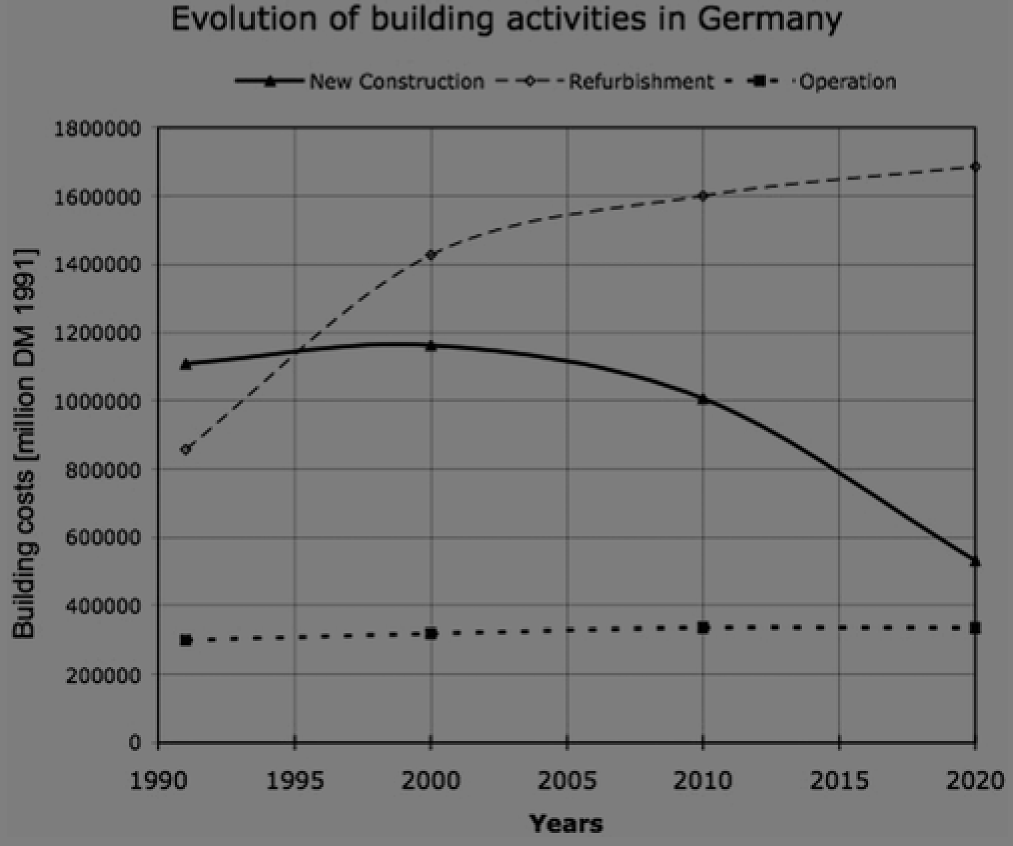

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Capital-based approaches

Resource economic approaches

Industrial sectors are generally described in flow-type approaches comparing output and capital and labour input, capital and labour productivity and the probable evolution of the demand. Environmental economists (Bromley, 1991; Pearce and Warford, 1993;

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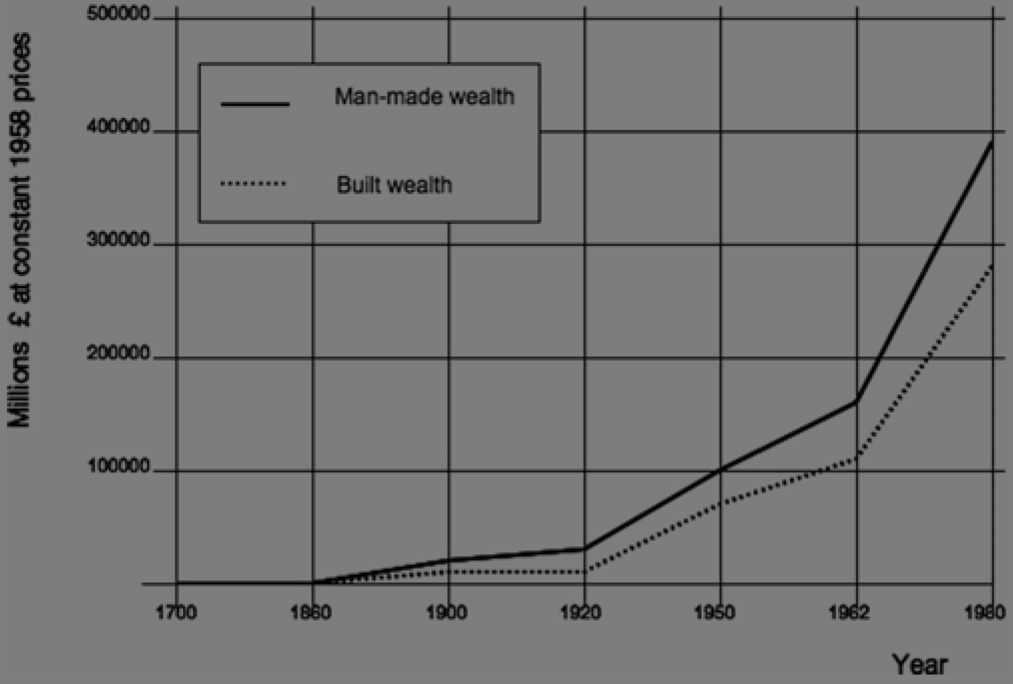

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An international comparison shows that the intangible capital (i.e. social, human, cultural capital) has the highest share in all countries (Table 1). The proportion of natural capital is higher in low-income countries even if in absolute value it is much lower than in high-income countries.

Table 1 Composition of the wealth of different types of countries in US$ per capita and percentage share. Oil states are excluded

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dominating part of the man-made, physical capital but it is also part of the social capital in the sense that it constitutes the place for social relations. In this sense, there is a clear relation between the quality of the environment and the quality of social relations. If the physical state of housing estates is decreasing, a number of the tenants leave the place and the social problems in the remaining population increase. In a similar way the built environment through his complex historical composition can only be maintained through well-trained professionals, i.e. through the existence of human capital. Finally, the building and infrastructure stock constitute a cultural capital that allows the society to develop an identity, that in turn is a form of social capital. The same arguments can be developed through the analogy of natural diversity, social diversity and cultural diversity as factors that will contribute to the resilience of systems. A sustainable development would therefore assure the increase (or at least the stability) of the different forms of capital and this can only be realized by substitution process. The amount and speed of transformation / substitution can in itself become criteria for sustainable development (Kohler, 2006a; Gunderson and Holling, 2002).

Institutional regimes

The mentioned capitals can be regarded as resources which produce goods and services which are allocated to different users/actors through so called institutional regimes (Knoepfel and Nahrath, 2005), i.e. combinations of use or property rights (Bromley, 1991) and public policies. These rights can take a multitude of forms. As long as there is no scarcity and no damage, resources can be used freely. This is, of course,
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optimum solutions or at least, constraint-satisfaction-type evaluations. An additional interesting property is that under-use as well as over-use of a resource can be a threat to the resource. This is also verified when considering urban fragments (neighbourhoods or smaller urban areas) as resources: high speeds of transformation, which can be associated with an over-use, and too low speeds of transformation, which can lead to dereliction, are both threats to a resource (Kohler, 2006b). The fact that in the construction sector there is less a scarcity of (natural) resources than a scarcity of (natural) sinks is another interesting conclusion from a capital (or resource) based approach.

Long-term dynamic of building and infrastructure stocks

Both in the flow-based approach and in the capital-based approach the consideration of long time periods is crucial. It is not a question of predicting the future (which is impossible) it is important to be able to imagine long-term scenarios that are based on long-term evidence (i.e. evidence from looking back). The assumptions on how long buildings and stocks last and why some have lasted and last longer than others is of course not only a physical question, the answers depend also on the context. However, the longer the period of time taken into consideration, the more the purely physical and statistically describable behaviour of stocks will become dominant.

Lifetime of buildings: service lifetime

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and consumption of fixed capital from time series of gross fixed capital formation. This also concerns service life.

Physical lifetime

In survival analysis of building stocks (Bradley and Kohler, 2007) one looks at building/infrastructure stocks backwards in time in order to find out how many objects have been built and how many have disappeared. These effective, physical, lifetimes seem to be much higher in central Europe than the usual assumptions of service life and economic life – at least for the older parts of the stocks. Similar conclusions can be derived from historical data obtained for residential and non-residential (Hassler and Kohler, 2004) buildings. A central issue is the mortality of buildings. Life tables of classical population dynamics (Klein and Moeschberger, 1999) can be used for estimating the mortality of a sample of building and infrastructure (Herz, 1998; Schiller, 2007) stocks. Special attention has to be paid to methods of data collection that seem to be a crucial point for the analysis building stocks in general. Test of fits of standard survival curves can also be performed for censored data. It is also interesting to compare building and infrastructure survival functions to survival functions of transport and production equipment (Figure 5).

Figure 5 Probability of survival and half-lifetimes for a German housing stock (A), German non-housing stock (B), German sewage infrastructures (C), an industrial sugar plant (D), American cast-iron buildings (F), and ships on Lake Geneva (G) (Kohler, 2004)

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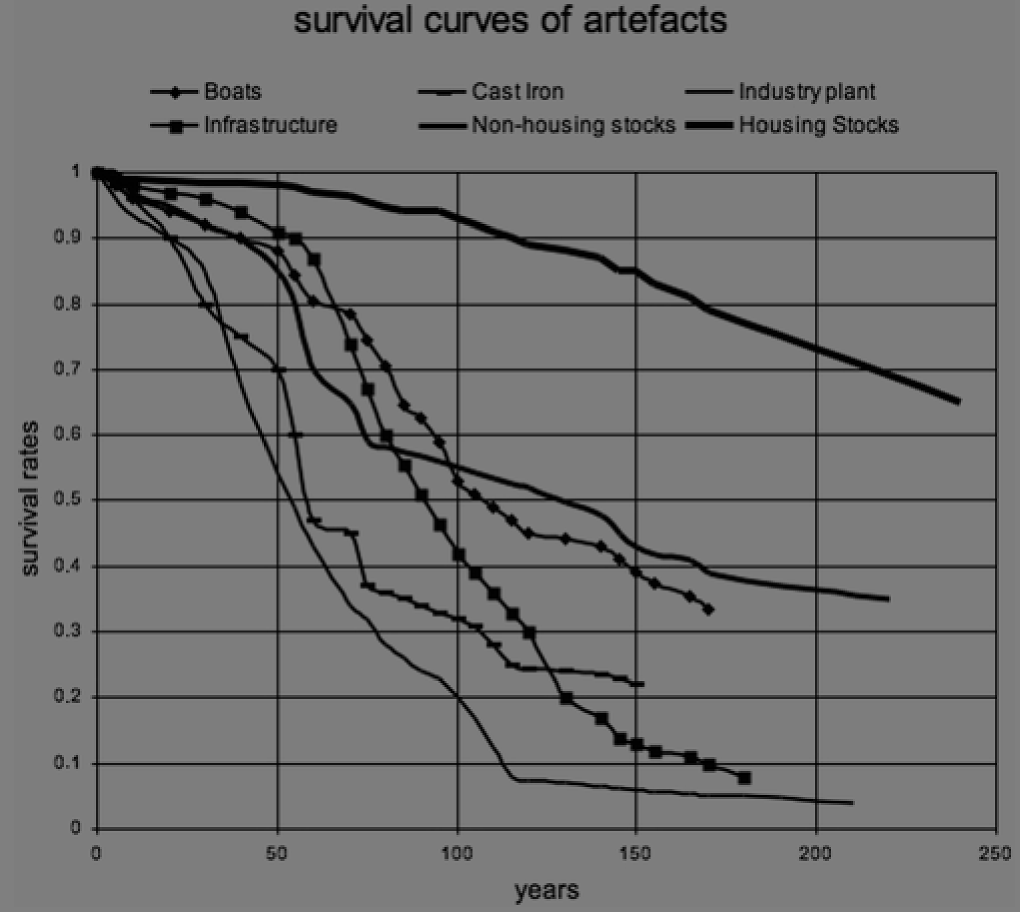

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In order to be able to make predictions on the building stock in the future, parametric survival function can be estimated. It appears that a log-log plot of the cumulative hazard function H(t)= − log S(t) could be linear, indicating that it is not unreasonable to assume a Weibull distribution for the survival function S(t). An effected Weibull fit yields that there should not be much change in the existing building stock in the next century (Bradley and Kohler, 2007) (Figure 6).

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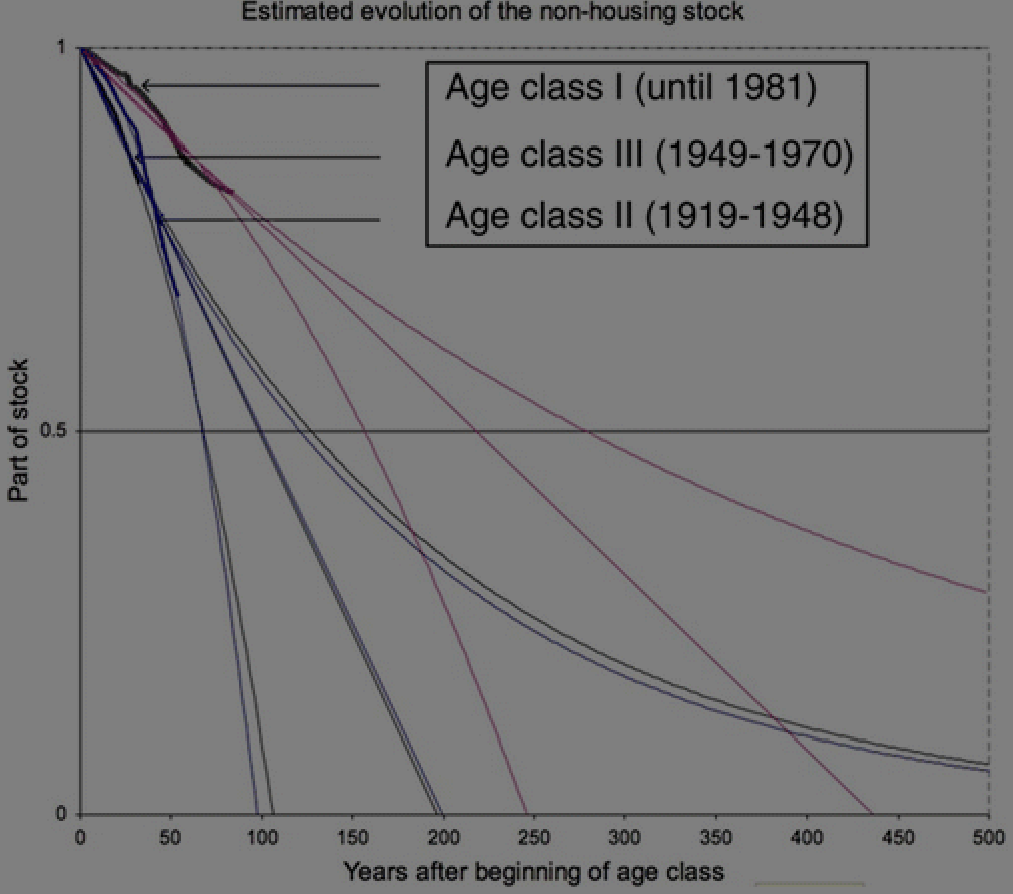

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The detailed analysis of particular (German) buildings stocks by establishing historical loss functions shows astonishingly high half-lifetimes of stocks (Hassler and Kohler, 2004; Kohler, 2004). Of course, the buildings have been refurbished and transformed many times during this period, but the volume, the bearing structure, the form and basic function remain. From the analysis of the survival functions of other stocks it appears that the older age classes have much higher survival probabilities, and that the newer age classes will disappear before the older ones.

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environmental impacts showing that identical results can be obtained either by reducing resource inputs and impacts or by raising the lifetime of the functional unit (spreading the inputs/impacts over a longer period). This is however only considering the conservation of the physical and economical capital, when we take into account the human, social and cultural capital values, long lasting solutions are largely preferable (Hassler and Kohler, 2001; Kohler and Hassler, 2002).

The link between the different types of service life (as a performance level to be obtained and guaranteed) and the effective lifetime of buildings resides in the difference between a reasonable (individual) planning decision and a (societal) interest to use the complex resource of the building stock in a sustainable way. This means that for the planning decision service life can be considered as the time for which a certain probability of survival (in the sense of the effective lifetime point of view) can be guaranteed. Thus, for many buildings, service life would be followed by a post-service lifetime. The parts of buildings that can technically last longer than the assumed service lives (foundations, structure, parts of envelopes and surfaces) should be easily maintainable. The subsystems that will eventually have to be replaced should be controllable and replaceable. Furthermore, certain reserves of space (e.g. floor heights), redundancy of distribution systems and lean (passive) technologies could be provided in the perspective of a possible ‘second service life’. These demands could take the form of societal, intergenerational demands, e.g. in the form of specific standards and recommendations. For a more detailed discussion, see Bradley and Kohler (2007).

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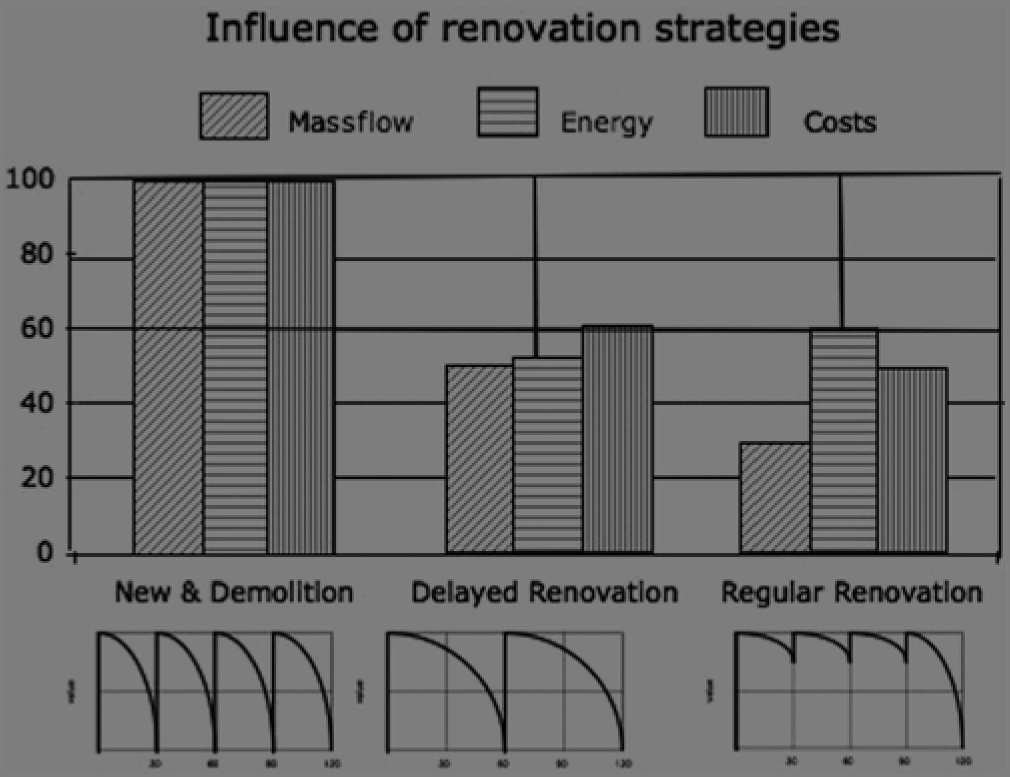
operation energy performance; from a resource and economic point of view they are not interesting. The land ownership and land price issue is not taken into account in this comparison.

Figure 7 Scenarios for renovations over 120 years taking into account the reduction of operation energy (for all scenarios) and the additional renovation and maintenance costs for delayed renovation. Relative values, the new and demolition strategy = 100%



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approaches are therefore more promising because they can handle both quantitative and qualitative constraints when defining an n-dimensional solution space. This is particularly important when dealing with institutional problems (Kohler, 2006a).

Crucial parameters of stocks

The behaviour of a stock can be modelled in variable depth and granularity. For strategic decisions a limited number of parameters have to be known. Second, derived parameters and indicators can later on be mapped to the basic parameters. Three types of parameters can characterize the existing part of the stock:

- State parameters: size and composition (possibly normalized to population), the average (or median) age of the buildings and infrastructures, and the state of degradation (the quality), which can be indicated by the difference between the present state of the stock (present value) and the state at the beginning (new value).
- Dynamic parameters: the rate of new construction, the rate of demolition (or the average physical life expectations), the rate of refurbishment (or the average interval between refurbishments). The new construction rate depends on social needs and on policy decisions, the demolition rate can be the result of many reasons, the important point is that both economic and physical capital is destroyed (waste production). The refurbishment rate is the real refurbishment rate. It must be compared to the normative (necessary) refurbishment rate to express a possible loss of quality in case of non-refurbishment or delayed refurbishment.
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described simple model can be applied to very different stocks. Two types of stocks with distinct properties will be discussed briefly.

Old, stationary building stocks of industrialized countries

These stocks have developed from the industrialization in the 19th century and have been doubled in the middle of the 19th century and once again in the mid-20th century (from 1950 to 1980). Since then, they are more or less well maintained by a combination of a low rate of new construction and high refurbishment rates. The refurbishment part is higher than the new building part and this tendency will continue for the coming 30 years. The key questions for the construction industry are according to Meikle and Connaughton (1994, p. 320):

(1) how to maintain the existing stock of housing in habitable condition and

(2) how to design and deliver adaptable and maintainable new housing.

The crucial indicator is the state of degradation of the different components of the stock. If the older cohorts are in bad state, it means that a high average lifetime is a disadvantage. If, on the contrary, the older cohorts not only survived longer, but are also in better shape (because better built), a high average age of the stock is an asset. There is a large debate at present on the consequences of regressive demography (and fast ageing population) in many European countries. In some regions the building and infrastructure stocks are already now too large and the influence of shrinking phenomena are not well known (Schiller, 2007).

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the global quality of the stock (physical, economic, social, cultural) will fast decrease. The resources that have been created by an enormous social effort and at a high environmental impact cost, will be destroyed before they can produce goods and services (harvest) over a longer period. Figure 8 compares the schematic evolution of two different stocks. For each stock the lower curve indicates the real available volume (or the demand), the upper curve indicates the necessary production to reach and maintain the demand volume. The difference is equal to the demolition volume resulting from the average lifetime of the buildings. The closer the doubling rate and the life span are the larger this difference. It can be seen that even if an emerging stock becomes stationary (assumed in 2050) the need for new construction will continue to grow if the life span of the buildings is of the same magnitude as the doubling rate. If this should happen in a very large country like China, there would be a dramatic shortage of available building materials and at the same a continuously high level of resulting environmental impacts. Of course, this model is very schematic and the conclusions should be verified through much more detailed models needing a large amount of validated input data. These data do not exist in most countries (industrialized or emerging); a need for international research collaboration is certainly apparent.

Figure 8 Comparison of the relative evolution of the gross floor surface of two stocks that will become stationary around 2050. The cumulated evolution is normalized to 100% in 2005 for the demand function. The demolition rate of the old stock is 0.5%; the demolition rate of the new stock 3%. The difference between demand and production represents the loss due to demolition

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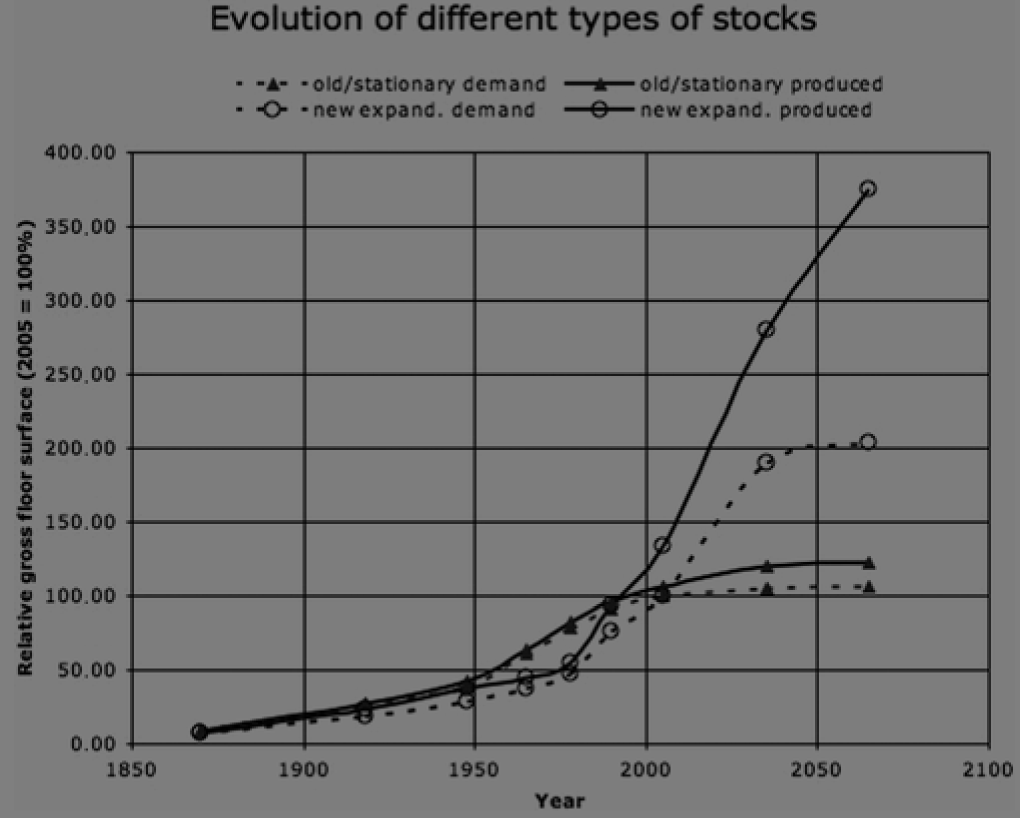

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Strategies

The long-term evolution of the building and infrastructure stock is one of the key aspects of sustainable development in all countries, even if the dynamics of the stock and the priorities are not the same. There is a growing awareness that this evolution cannot be controlled by simple market mechanisms, investment incentives or standards. The briefly described institutional approach is more promising when dealing with long-term and complex societal issues like the evolution of the building and

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importance of institutional regimes in very different situations can be given for the long-term capital conservation of housing estates. In the case of rapidly expanding stocks, simulations show that the construction quality of the load-bearing structure has a strong influence. In a similar way the refurbishment rate and quality is a crucial parameter in old, stationary stocks. Assuming in both cases a public policy of sustainable development, the forms of property in housing are determining for the long-term outcome. State-owned housing with insufficient investment or insufficient quality claims can and do lead to dereliction within one generation. Mass privatization of public housing can lead to situations, where the individual ownership makes the necessary refurbishment necessary for the long-term conservation of urban capital (physical, economic, social and cultural), difficult. Individual owners do not have the same abilities to finance the refurbishment work and to obtain professional high quality work, as corporate or public owners of large numbers of flats (Meikle and Connaughton, 1994). In the same way individual owners do not have the necessary information and ability to judge the long-term quality of the construction. It appears that only public policies combined with differentiated forms of use and property rights and access to qualified information can assure a long-term capital conservation.

It is striking to see that in many countries (industrialized and emerging) there is an attempt to solve the problem of subsistence of the retired population through private ownership of housing. The pension funds also invest in housing projects expecting high rates of return to guarantee the pensions. These measures are supposed also to solve the problem of reduced demography (voluntary or not) and the resulting ageing of the population. There is a considerable risk that the present institutional regimes developed
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Conclusions

The building and infrastructure stock is the largest physical, economic, social and cultural capital of most societies. Its evolution is a crucial parameter in sustainable development. The composition of stocks and their long-term behaviour are not well known. The establishment of long-term scenarios faces severe problems of data collection on the past behaviour of stocks. The uncertainty issue in all long-term scenarios is only very partially considered. A bundling of international research efforts is necessary to advance rapidly in this highly sensitive knowledge field. A possible combination of flow- and capital-based approaches taking into account institutional regimes could be a promising basis for necessary long-term scenarios. The long-term institutional aspects have to be taken into account to avoid dramatic losses of economic, social and cultural capitals in the coming decades.

Acknowledgements

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References

1. Bartelmus , P. , Bringezu , St. and Moll , S. 2001 . Dematerialization, Environmental Accounting and Resource Management , (available at: http://europa.eu.int/comm/environment/enveco/studies2.htm#26)
 Google Scholar

2. Bradley , P. and Kohler , N. 2007 . A methodology for survival analysis of urban building stocks . Building Research & Information , 35 (5)
 Web of Science ® | Google Scholar

3. Bromley , D. W. 1991 . Environment and Economy. Property Rights and Public Policy , Oxford : Blackwell .
 Google Scholar

4. Cowan , P. 1963 . Studies in the growth, change and ageing of buildings .
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7. Hassler , U. and Kohler , N. 2001 . “ Cultural and environmental long term strategies for the built environment ” . In Rational Decision-making in the Preservation of Cultural Property , Edited by: Baer , N. S. and Snickars , F. 235 – 248 . Berlin : Dahlem University Press .
Google Scholar

8. Hassler , U. and Kohler , N. 2004 . Über das Verschwinden der Bauten des Industriezeitalters , Tübingen : Wasmuth .
Google Scholar

9. Herz , R. Exploring rehabilitation needs and strategies for drinking water distribution networks . Proceedings of the 1st IWSA/AISE Conference . Prague, Czech Republic.
Google Scholar

0. ISO . 1997 . ISO CD 14 040.2 Life Cycle Assessment – Principles and Guidelines , Geneva : ISO .
Google Scholar

1. ISO . 2000 . ISO 15686-1. Buildings and Constructed Assets — Service Life Planning. Part 1: General Principles , Geneva, Chiswick : ISO, BSI .
Google Scholar

2. Johnstone , I. M. 1994 . The mortality of New Zealand housing stock . Architectural Scienc

3. Klein , for
Censo
Go

4. Knoep Resources ,
Lausa
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5. Kohler , N. 2004 . Industriell gefertigte Bauwerke als Langzeitprodukte Karlsruhe Internal Report ifib, (available at: http://www.ifib.uni-karlsruhe.de/download/Ind_Lang.pdf)
Google Scholar

6. Kohler , N. 2006a . A European perspective on the Pearce Report: policy and research . Building Research & Information , 34 (3) : 287 – 294 .
| Web of Science ® | Google Scholar

7. Kohler , N. 2006b . " Life cycle analysis of buildings, groups of buildings and urban fragments " . In Sustainable Urban Development: The Environmental Assessment Methods , Edited by: Deakin , M. , Mitchell , G. , Nijkamp , P. and Vrekeer , R. 348 – 371 . London : Blackwell .
Google Scholar

8. Kohler , N. and Hassler , U. 2002 . The building stock as a research object . Building Research & Information , 30 (4) : 226 – 236 .
| Web of Science ® | Google Scholar

9. Kohler , N. , Hassler , U. and Paschen , H. 1999 . Stoffstroeme und Kosten im Bereich Bauen und Wohnen. Studie im Auftrag der Enquete-Kommission des deutschen Bundestages 'Schutz des Menschen und der Umwelt' , Edited by: Kohler , N. , Hassler , U. and Paschen , H. Berlin : Springer .
Goog

20. Kohler lding
Resea

21. LC (available
at: LC
Goog

22. Meikle ? Some

Management and Economics , 12 (4) : 315 – 321 .
Google Scholar

23. Meinem , G. , Verbiest , P. and deWolf , P. P. 1998 . Perpetual Inventory Method: Service Lifes, Discard Pattern and Depreciation Methods , Voorburg : Statistics Netherlands .
Google Scholar

24. Pearce , D. 2003 . The Social and Economic Value of Construction: The Construction Industry's Contribution to Sustainable Development , London : nCRISP .
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25. Pearce , D. 2006 . Is the construction sector sustainable? Definitions and reflections . Building Research & Information , 34 (3) : 201 – 207 .
Web of Science ® | Google Scholar

26. Pearce , D. and Warford , J. J. 1993 . World Without End: Economics, Environment, and Sustainable Development , Oxford : Oxford University Press .
Google Scholar

27. Schiller , G. 2007 . Urban infrastructure – challenges for resource efficiency in the building stock . Building Research & Information , 35 (4) : 399 – 411 .
Web of Science ® | Google Scholar

28. Stead gy of the
Englis , 18 (1) :
85 – 9

29. Wo r the 21st
Centu ank.org)
Goog

30. Yang , a

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31. Yang , W. and Kohler , N. forthcoming . Simulation of the evolution of the Chinese building and infrastructure stock . Building Research & Information ,
Web of Science ® | Google Scholar

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