Hard and soft science issues to be negotiated to improve urban metabolism

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Introduction

In the industrialised world, waste management systems have developed to maturity without primary concern for recycling. These systems have originally been designed to ensure human health and a high local hygienic standard. More recently environmental concerns have been the driving force behind a technological development of sewage treatment with biological removal of N, P, and organic matter. This technology addresses some immediate problems in the aquatic environment, but the sewage sludge from the treatment plants contains considerable quantities of xenobiotic compounds and heavy metals, and only a fraction of the nutrients that entered the urban areas, thus making the sludge a non-attractive fertiliser source. In recent years there has been concern about the sustainability of this state of affairs as regards wastewater handling, as well as concern about the fate of the final waste deposits in the environment. In the mid 1990s Danish organic farmers made a point of refusing to accept sewage sludge as a source of nutrients. This sparked a heated debate, and for a time all farmer organisations refused to accept sewage sludge on their fields, leading to severe problems in urban areas. One of the consequences of this conflict is that municipalities are increasingly seeking alternatives to returning sewage sludge to the land (e.g. burning or dumping), in order to rid their dependence of farmers' acceptance.

Another consequence has been that the issue of 'closing the urban-rural nutrient circle' as part of a sustainable development has received increasing attention among Danish organic farmers. This issue had been identified already in the early days of the organic movement in Denmark, but has never been a top priority. It was accentuated by a strong Swedish emphasis of agricultural use of human urine from source separating toilets that provided inspiration to look at implementing such techniques in Danish urban areas.

One additional factor that has increased the priorities of the issue was the growing realisation that current day organic farmers have a strong bias towards milk production, due to the natural integration of the clover-grass in the production system, that is essential for ensuring an ample supply of fixed atmospheric nitrogen. If more stockless organic farms (e.g. vegetable and grain production for human consumption) are to become economically sustainable, it is important to find ways of using the land with less emphasis on clover grass. One of the ways of doing this is to increase the amounts of nutrients that can be re-cycled from urban areas in a form that is acceptable to organic farms.

Box 1 The NUTRAP centre

Central to the strategy for working towards closing the urban-rural nutrient cycle has been the formation of

NUTRAP

CENTRE FOR APPROPRIATE TECHNOLOGIES FOR NUTRIENT RECYCLING FROM HUMAN WASTE TO AGRICULTURE IN PERI-URBAN AREAS

At present the following institutions have signed a memorandum of understanding to this end:

The Departments for Agricultural Sciences and Veterinary Microbiology, KVL
The Department for Environment and Resources, DTU, and
The National Environmental Research Institute (DMU)

Link to: www.agsci.kvl.dk/nutrap

Identification of urban fertiliser potentials

Recycling from the food and other bio-processing industry waste has been estimated to be approximately 99% in Denmark (Danish EPA, 1998) since waste from this sector is either used for fodder or fertiliser directly or after bio-gas production. Based on this assessment it was decided that there was little need to include industrial wastes in the view of improving re-circulation.

However, the waste management in urban households, service sector, and other industries poses a separate challenge. State-of-the-art systems are based on collection of solid waste (often separated in an organic and non-organic fraction) and treatment of waste-water. The sewage systems receive black water (physiological fraction), grey-water (washing and cleaning), and storm water runoff. The composition of waste sources from households in Scandinavia (table 1) clearly indicates that the urine and faeces fraction contains by far most of the nutrients in the household waste. Thus night soil together with the solid organic household waste theoretically constitutes app. 1% of total household waste volume, but contains 82-87% of the nutrients. By removing this nutrient rich household waste the need for nutrient removal from sewage would be minimal or non-existant (see figure 1).

Table 1 The composition of waste sources from households in Scandinavia (grams per person per day) and their relative contribution to weight and nutrient content. Modified from Magid et al. (1999)

	Total	Physiological		Kitchen		Bathroom
		Faeces	Urine	Liquid	Solid	Grey water
Dry matter	235	35	60	40	80	20
Chemical oxygen demand	220	60	15	45	90	10
Biological oxygen demand	90	20	5	30	30	5
Nitrogen	15.7	1	11	1	1,7	1
Phosphorus	2.8	0,5	1.5	0.2	0.3	0.3
Potassium	4.7	1	2.5	0.4	0.4	0.4
Contribution to waste weight (%)		0.1	0.8	7	0.3	91.7
Contribution to N in waste (%)		6	70	6	11	6
Contribution to P in waste (%)		18	54	7	11	11
Contribution to K in waste (%)		21	53	9	9	9

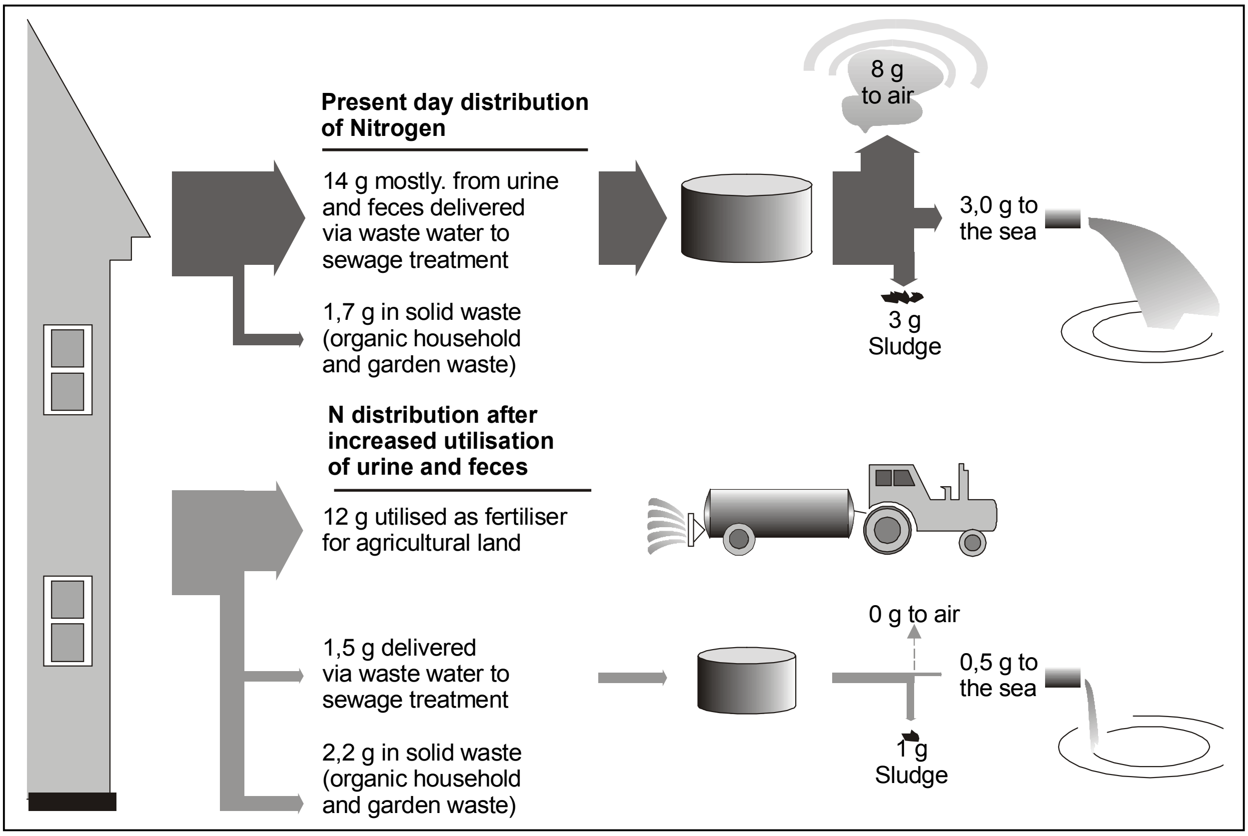


Figure 1 Conceptual diagram of Nitrogen distribution from households (per person per day) in present day and future sanitation systems (delivered by Eilersen and Henze, IMT, Danish Technical University)

In practice, systems need to be developed in order to manage this nutrient rich household waste from urban areas, but a realistic estimate based on minimal flushing systems indicates the volume of this nutrient rich waste to be no more than 2-3 m^3 $person^{-1}$ yr^{-1}, as the volume of urine (450 l), faeces (60 l), and organic household waste (150 l) in itself will be less than 0.7 m^3 $person^{-1}$ yr^{-1}. In Scandinavia such systems have been developed and tested for rural areas without sewage systems, and currently trials with such systems are being made in urban areas.

Waste streams in urban areas can be handled in a number of different ways, giving rise to different products. In table 2 an overview of the findings on present day and future urban fertilisers is given.

Nutrient recycling is not the only consideration with respect to waste handling. It is important to look at the total waste generation as well as at the total waste handling system, and attempt to reach an overall optimal system. Recycling nutrients in itself probably does not balance the costs of implementing changes in waste management, if handling of other waste streams gives growing problems.

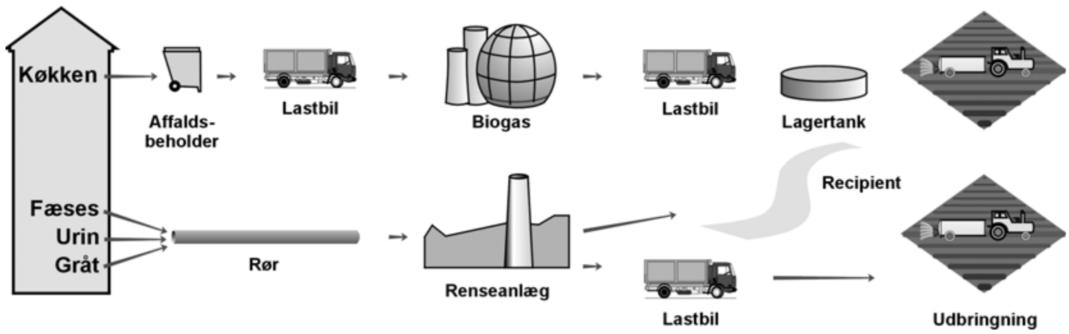
The maximum amount that can be recycled from the urban areas would cover no more than 5% of the current day nutrient input to agriculture (Magid et al., 1998), although in certain parts of the country (metropolitan areas) most of the agricultural nutrient demand could be supplied from urban areas. While the figure of 5% may seem low it should be seen in the context that Danish agriculture is highly intensive, based on imports of feed and fertilisers that are necessary to ensure the present production levels of meat and milk products for exports and, therefore, the off-take of our urban population appears small. It can be discussed if this general state of affairs in Danish agriculture is sustainable in the long-term. It is, however, undeniable that recovering 5% of the current day agricultural nutrient flow could sustain a considerable food production for local consumption.

Table 2 Overview of the findings on present day and future urban fertilisers (based on Magid et al. 1998)

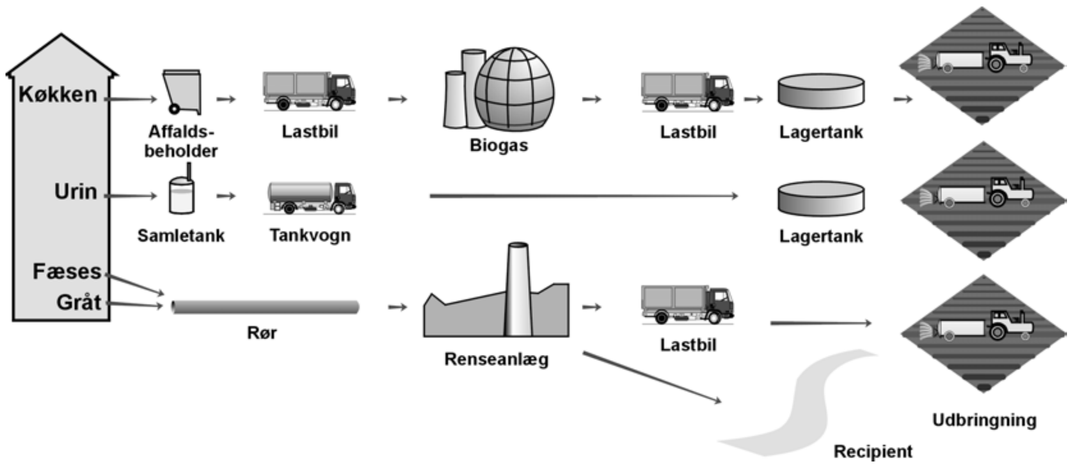
	Product	Comment
Cities of today	Sewage sludge	Rich in P, but poor in most other nutrients, notably N, K, S, and some of the micro-nutrients. Considered a dubious fertiliser because it is very unbalanced and contains unknown quantities of xenobiotics. Problems with heavy metals may occur in the longer term. Hygienic risks have been considered in the currently implemented law on agricultural use of waste products.
	Composted household waste	There have been problems with too high contents of heavy metals (mostly solved). Little hygienic risk beyond the initial pre-composting handling. If the compost is dominated by garden waste it may work better as a soil conditioner than as a fertiliser. Hygienic risks have been considered in the currently implemented law on agricultural use of waste products.
	Ashes from bio-fuel heat and electricity plants	Rich in K and S and some micro-nutrients. In the combustion plant a sorting of the ashes takes place. Some of these should be avoided, since they contain high amounts of heavy metals
Cities in the future	Sewage sludge	See above. Will be present in the cities for many years to come, due to the high investment in the present day infrastructure. May become less problematic, if xenobiotics become increasingly phased out of the matter streams
	Human urine	Well-balanced nutrient source. With appropriate storage it does not impose hygienic risks to handlers, nor to consumers of fertilised product, according to Swedish health authorities.
	Composted faeces/household waste mixture	See above. Introducing human faeces may increase risks during handling, whereas risks afterwards are unknown
	Degassed faeces/household waste mixture	Have not been successfully implemented in Denmark either with or without human faeces. Health risks are not well known, but considered acceptable based on general knowledge. Current installations are mainly fed with animal manure, fat containing industrial wastes, and/or sewage sludge.
	Ashes from bio-fuel heat and electricity plants	See above

Assessment of possibilities and barriers for recycling of nutrients from urban areas to peri-urban agriculture

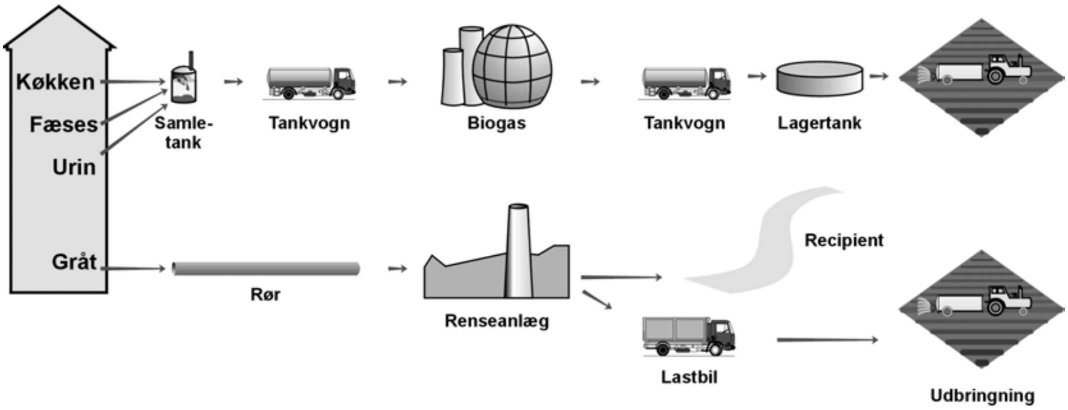
In a recent project, 14 handling systems for domestic wastewater and organic kitchen waste have been described and evaluated (Wrisberg et al., 2001). A method for choosing systems for different housing areas in a city was developed. The method was used for the city of Hillerød with 26,000 inhabitants, where four handling systems where chosen. These systems are graphically illustrated in figure 2 below. There are several advantages from using the four systems instead of the already existing sewer system. The energy surplus was the same as the energy consumption for 900 households, the nutrients collected within the systems were enough to fertilise 451 hectares of agricultural land. The yearly costs were estimated to be 17% higher than in the existing system.



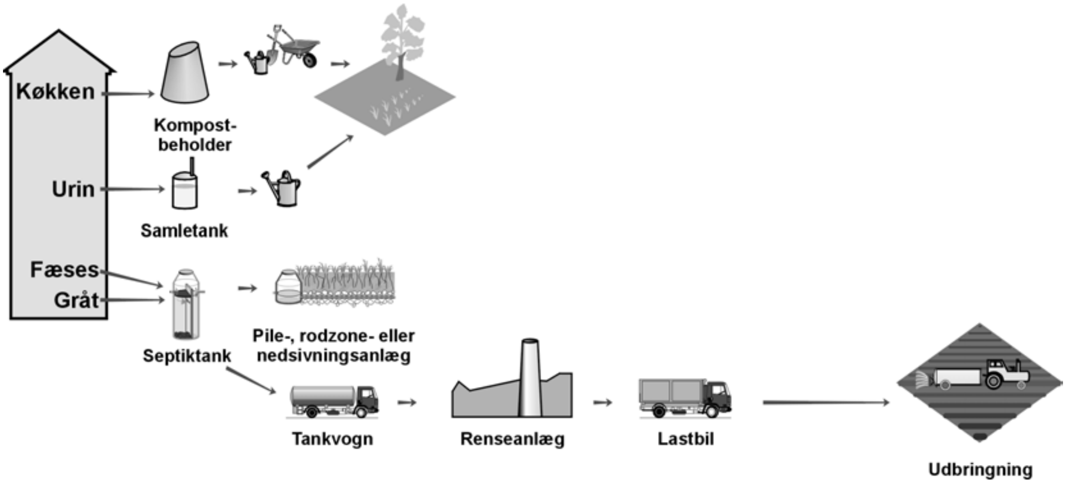
System 1: Kitchen waste is treated in a biogas plant. Urine faeces and grey water are treated in a wastewater plant.



System 2: Kitchen waste is treated in a biogas plant. Urine is collected separately, faeces and grey water are treated on a wastewater plant.



System 3: Kitchen, faeces and urine are treated in a biogas plant, grey water is treated on a wastewater plant



System 4: Kitchen waste and faeces are composted. Urine is collected while grey water is infiltrated into soil.

The pertinent scientific issues

Based on the work we have done so far, we have identified a number of wider issues that need to be addressed by research in the future:

a) Housing forms allowing recycling

b) Technologies for waste and water stream management

c) Health and hygienic risks

d) Ecosystem integrity and soil health

e) Environmental risks

f) Agronomic potential of urban fertilisers

g) Cultural acceptability

h) Economic viability

In the section below some background knowledge for a few of the identified issues is discussed in some detail, with a view to presenting a qualified approach for dealing with the problems.

Perceived threats to the environment and to the ecosystem integrity

The most imminent threat to the environment and the ecosystem integrity is related to transfer of disease vectors from urban fertilisers to animals or humans. However, since the 'Urban metabolism' is far from understood and not really under control, it is not possible to foresee which unintended effects the use of urban fertilisers may have on soil quality and the surrounding environment. This is a further justification for developing a long-term trial (see Box 2), in order to ensure that any such effects can be observed in time to prevent problems in the a context. Unknown quantities of unknown organic xenobiotic compounds may occur in sewage sludge. Similarly, human urine will contain quantities of medicinal substances that have been secreted from the kidneys, as well as chemicals from whatever detergent that has been used for cleaning the toilet. Heavy metals are a part and parcel of modern life, e.g. copper tubes in buildings, zinc on roofs, and many other surfaces as well as in cosmetics and shampoo. Thus in sewage sludge the heavy metals cannot be avoided in concentrations above what would be expected if the only contributing factor was the content in food delivered from agriculture. Even in human urine it is conceivable that contamination from tubes and storage tanks may occur. There is little available knowledge on long-term effects of various xenobiotics. However, in recent years a considerable body of knowledge has been gained on the effect of moderate increases in heavy metal concentrations in soil on some key biological processes.

Generally, heavy metals in soils are only plant available to a very limited extent, due to their reactivity within the soil matrix. Many of these are described as micro-nutrients (e.g. Cu and Zn), since they are only taken up in very small quantities and are essential for the completion of the plant life cycle. Therefore, only few observations of damages to plants or to animals and humans through the transmission of heavy metals in the food chain via plants have been reported. On Woburn Experimental Farm, the Market Garden Experiment was established in 1942, at a time when the supply of industrial nitrate was strictly limited to use for ammunition, due to the ongoing war. Among the treatments examined was heavy metal contaminated sludge from London's sewage works. These experiments were terminated after 20 years at which time the heavy metal concentration had increased substantially in a number of treatments. These plots were used afterwards to study the uptake of heavy metals in various crops, and virtually no ill effects were observed, except in red beet, which is especially sensitive to certain heavy metals (McGrath, 1987).

Therefore, it came as a surprise when clover sown in the sludge treatments was sickly and yellow, while clover growing on uncontaminated plots was healthy and dark green (McGrath, 1994). Closer inspection of the diseased clover revealed that the roots had not formed normal pink nodules that legumes usually form with nitrogen fixing bacteria. These observations could be repeated in the laboratory, while poor growth of clover could be alleviated by addition of inorganic nitrogen. Use of ^{15}N clearly indicated that clover growing in contaminated soils had lost its N-fixing capability (McGrath et al., 1988). Furthermore, plants growing in the contaminated soils failed to form VA-mychorrhizal associations. These results have been corroborated by independent observations from sludge treated soils from Braunschweig and has led to a comprehensive European effort to understand the causes for these very considerable reductions in soil quality. One of the crucial issues in this regard has to do with the very long-term impact of heavy metal accumulations in soil, since they are not 'biodegradable'. Thus, according to Witter (1996), it will take anything from a few thousand years up to 180,000 years for soils to decontaminate naturally, once they have been loaded with a certain (moderate) amount of heavy metals.

One of the most important lessons from the work on heavy metal impact on key biological soil functions was the realisation that addition of heavy metals to soil did not result in acute toxicity, and only prolonged exposure (18 months) provided effects comparable to those observed in the field trials (Chaudri et al., 1993). It is currently believed that the delayed response of nitrogen fixing bacteria to heavy metal pollution is caused by the transfer of plasmids from resistant Rhizobia to non-resistant forms, and that the transfer of this plasmid results in a deactivation of the bacterial nitrogen fixing capacity, while at the same time it delivers heavy metal resistance (Ken Giller, personal communication). This work, like no other, demonstrates the need for long-term field experiments for proper evaluation of unintended effects on soil quality and ecosystem integrity.

The way forward

Changes in soil quality occur gradually and will often not be measurable until the soil has been treated systematically over a number of years. Therefore, the long-term trials with urban fertilisers must be undertaken in order to assess such effects. We have successfully developed a proposal (see Box 2) for a research project on the use of urban fertilisers.

Box. 2 A brief description of the CRUCIAL project, which has been financed to run from August 2001 until August 2006

CRUCIAL

Closing the Rural-Urban Nutrient Cycle

WP	Work Package	Responsible
1	Establishment and running of long-term field trials with urban fertiliser	Jakob Magid, Royal Veterinary and Agricultural University
2	Developing composting practices for household waste and human faeces	Jakob Møller, Danish Forest and Landscape Research Institute
3	Carbon and nitrogen dynamics associated with use of urban fertilisers	Jakob Magid, Royal Veterinary and Agricultural University
4	P turnover in soils ammended with urban fertilisers	Bent Christensen Danish Institute of Agricultural Sciences
5	Monitoring soil quality	Poul Henning Krogh, National Environmental Research Institute

a) Dept. Agricultural Sciences has commited itself to run the experiment over a long-term period (>15 yr)

It is expected that the CRUCIAL project will provide opportunities for addressing a number of the issues identified above, i.e. "health and hygienic risks", "ecosystem integrity and soil health", "environmental risks", “agronomic potential of urban fertilisers", and in part "cultural acceptability" as well as “economic viability".

However, the work that will be carried out in connection with the coming CRUCIAL project will mainly be able to tackle biological and environmental issues, and only to the extent that a wider public interest is generated by this work it will be able to touch upon the socio-cultural issues.

Thus we face the problem of finding a way in which to integrate the divers issues within research that have been identified above as being essential to improve the urban metabolism. Given that we are still in a developmental stage, in which integrated waste management solutions have not been fully tested and proven in terms of technical, biological, and cultural measures of acceptability, the appropriate units for testing and developing solutions should not be very large.

It would be very relevant to develop co-operation with existing or planned smaller housing areas (50-150 persons) in which there is an interest in making such systems work that takes care of all the waste in an integrated way. This would provide a testing ground that would allow a realistic assessment of a large number of technical, biological, and cultural issues, and the supply of urban fertilisers would be sufficient for an experimental farm.

At a later stage, the expansion of such solutions to larger urban enclaves (2,000-10,000 persons) would allow a recycling of nutrients and organic matter on a scale that would be economically interesting both for the farmers involved and for the society as a whole.

Sectoralisation and specialisation within disciplines

Apart from the issue of funding, it is clear that one of the major challenges rests with the division of competence among ministries and sectors of society responsible for agriculture, housing, health, and environment. This is also reflected in the sciences that are required to contribute to a solution – there are not many examples of R&D projects integrating technical, biological, and socio-cultural sciences.

In order to bridge the gaps between ministries and sectors it is probably necessary to involve the politicians, since the bureaucracies tend to avoid taking responsibility for complex issues. In order to bridge the gaps between the sciences, it is necessary to choose appropriate study areas (housing areas) and go outside the laboratories and offices and start working together.

This process will be dependent on a complex interplay between scientists, grass roots, bureaucrats and politicians. It remains to be seen if the development of improved urban solutions will be successful – we will do our best to make it happen.

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