IDENTIFYING THE COMPLEX INFORMATION REQUIREMENTS OF SUSTAINABLE DRAINAGE SYSTEMS

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The management of water both for supply and removal is a growing concern of society. The primary purpose of sustainable drainage systems (SuDS) is to address the flow and volume of run-off from impermeable surfaces that are formed in the development of the built environment. SuDS involves a number of methods to store run off and release it in a controlled manner and to permit infiltration into the ground. This is often achieved through a ‘management train’ involving a number of methods arranged in a series and a number of landscape features such as basins, swales, permeable paving, grass filter strips, gravel strips and soil infiltration. Designing these effectively produces many benefits other than water removal including groundwater recharge, water resource, landscape enhancement and biodiversity. However, this requires addressing multiple objectives which make the problem extremely complex and involves the support of many disciplines and stakeholders. It has been proposed that infrastructure information modelling will make the design and management of SuDS easier and more robust. In order to explore the viability of this, this paper identifies the multiple and complex information requirements in the design and management of SuDS through an analysis of a design case study. It considers the different stakeholders and their different information needs. Information is of various types and qualities which forces a developmental approach to design. These differences are not acknowledged in current infrastructure information modelling which seeks to automate the process in a single comprehensive model. The paper concludes that new forms of models need to be created that can use different information qualities and allow a more interactive design between stakeholders.

Keywords: multiple models, complexity, decision making, stakeholders

INTRODUCTION

Water is a fundamental necessity for humans but it is significantly problematic characterised by drought or flood. The human management of water has been undertaken for millennia and the success of this was needed for societies to flourish. The management of water has developed over time seeking improvements by managing more comprehensively, faster and with greater certainty. Sustainable Drainage Systems (SuDS) are the default method for surface water management of new developments in the UK and are now being retrofitted in locations where flood prevention can be enhanced (Boscher *et al*., 2007). The basic purpose of SuDS “is to mimic, as closely as possible, natural drainage of a site in order to minimise the impact that urban development has on flooding and pollution of rivers, streams and

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other water bodies" (Wilson *et al*., 2004). SuDS therefore reduces flooding and pollution by providing natural methods of drainage like swales, ponds, basins, infiltration trenches, green roofs and wetlands. Other methods can also be employed such as permeable paving and rainwater harvesting, which may not be natural, but which allow for water to be stored and infiltrate into the ground similar to natural systems or to recycle water for use. As the beliefs in undertaking this SuDS water management have increased, many other advantages of SuDS have been realised for example: groundwater recharge, pollution control, landscape amenity, energy supply, and biodiversity enhancement. These increasingly complex requirements are making it more difficult to design effective and efficient systems.

The construction design world is being challenged to enter the digital information era, particularly as Building Information Modelling (BIM), in order to construct buildings more effectively, cheaply and faster. Although there is less impetus, a similar development is happening with infrastructure (Stasis *et al*., 2012) with its greatest drive being in railways, bridges and roads. It would appear that there are many opportunities for developing Infrastructure Information Modelling that would allow the more accurate design of systems more rapidly but also the integration of many more features into design and the delivery of greater certainty. What Infrastructure Information Modelling needs to be is an integrated platform for collaborative working bringing different computer modelling packages together and providing a repository for the extensive information that can be managed in the long term. However, there is very little development of comprehensive models in the SuDS field. This is strange as this field is heavily engineering based and has been using calculative methods and computer modelling for many years.

The success of the modelling world in changing the way manufacturing engineering design and development have been undertaken is legendary (Bailey 2012) with Finite Element Analysis and Computational Fluid Dynamics being ubiquitous tools now for the analysis and design of many systems. There is a question then about why SuDS has not been one of the first to develop an integrated information model. This paper will investigate this by considering the nature of the SuDS modelling problem and what information is required to make decisions on the design and management of such drainage systems. The work takes a critical look at modelling as a whole by exploring how information is transformed into knowledge through the analysis of a case study of a design situation. It considers the different stakeholders and their different information needs. Information is of various types and qualities which forces a developmental approach to design. Design involves complex multi-party judgements which are not acknowledged in BIM based infrastructure information modelling which seeks to automate the process in a single comprehensive model. The paper concludes that new forms of models are needed which work with these different information qualities, which inform the decision process, and which allow a more interactive design between stakeholders.

METHODOLOGY

The research reported here sought to gain a richer understanding of design approaches and the use of models for SuDS. This required an understanding of knowledge about drainage and natural environments and also of decision making with this knowledge. This work took a critical realist position (Mingers 2000) and used case study methods as the exploration was in a pilot phase. A single case study was used as this was sufficient to present the complexity of the design and modelling situation. The case was based on the design work of one of the authors which allowed an added insight into the problematic nature of design. Any bias from this was considered less important in this pilot work; the access to rich data being most important at this stage of the research. Mingers (2008) work is particularly suitable for the analysis of information systems as it provides a breakdown of knowledge. Mingers (2008) discusses the fundamental issue of the way that knowledge relates to truth. He questions how we accept what knowledge is arguing that there is not just one kind of knowledge or truth. The idea that data, information and knowledge are different has been discussed by Grover and Davenport (2001) who put knowledge at the top of the hierarchy which they deem to be information supported by insight, experiences, context and interpretation. Mingers (2008) offers four different types of knowledge: propositional, experiential, performative and epistemological. This breakdown is used to explore the case study and the more general SuDS design situation. Propositional knowledge is knowing based on combining declarative statements; experiential knowledge is based upon our personal experience of situations; performative knowledge is knowing how to do something in a social situation; finally, epistemological knowledge is knowing as a result of formal logical methods.

THE NATURE OF THE SUDS DESIGN PROBLEM

The SuDS design problem is technical, economic and social. In its basic technical analyses SuDS involves a hydrological model. Early hydrological models were lumped deterministic models which dealt with entities and variables as single units for example rainfall and runoff (Lundin *et al.*, 2000). These enabled a gross understanding of situations but were not useful for details of local design. As these models were developed they could represent more physics of the situation which allowed much clearer analysis with information tied more closely to real features of a situation. These physically based distributed parameter models were then developed in 3 dimensions using meshes which allowed them to be connected to maps (Abbott *et al* 1986), and with the advent of low cost computers allowed the adoption of digital techniques within the field.

Much of the current approach has been developed through experience and uses empirical equations developed a number of years ago (Marshall and Bayliss, 1994) rather than fully modelled analyses. In current approaches (Ellis *et al*, 2011, Wood-Ballard *et al.*, 2007, EA 2010) designers need to know details of topography, level and type of pollutants, soil permeability, groundwater level, volume of flow and permissible discharge rate from the site. Engineers therefore use design software which allow analysis of the hydrological aspects which consider supply of water, flows of water and how the landscape stores this; this permit them to set sizes and levels for the various components. The key input data is rainfall. Future rainfall cannot be known for any instance but must be estimated by intensity, duration and likelihood from past data. Design is then conducted against once in one-year events which occur frequently, once in 30 year events which present the maximum capacity of the system and finally 1 in 100 year events which present the consequences and risks of flooding.

However, these basic requirements are now being extended and the issues that need to be considered are increasing and this is changing the way that choices are made about various SuDS elements and therefore SuDS design has become much more complex. In the last 15 years there has been much more attention to pollutants, with particular focus on their impact on sensitive underground aquifers (Ellis *et al.*, 2012, Woods-

Ballard *et al*., 2015). This introduces both particulate pollutants and chemical pollutants to the situation which require different approaches to design. This requires models to be able to assess chemical and biological transfer and reaction (Hatt *et al*., 2007) which are based on a totally different basis to hydraulic models. Given that the variability and uncertainty of the situation is so evident, hydrological modelling has also been based on stochastic analysis which produced statistical data (Wagener *et al*., 2001). This working with uncertainty of the situation has also been developed using neural networks and Bayesian techniques.

The design situation is also socially constrained. In practice this involves consideration of land ownership and amenity value to satisfy planning conditions. This often requires Landscape Architects to be involved to consider proposed ground contours and sympathetic planting schemes again introducing a different perspective on the modelling. Inevitably, the cost in relation to benefit of the solutions adopted are challenged and the stakeholders argue about responsibilities for payments (Royal Haskoning, 2012) again producing different perspectives on approaches and solutions.

In order to try to rationalise the complexity of the situation so that decisions could be made, Ellis *et al*., (2011) devised a decision support system (DSS). This identified the key criteria needed to ensure that all requirements are satisfied or at least addressed. Table 1 shows the key criteria which the various stakeholders wish to be satisfied and the indicators which allow each of the criteria to be investigated and satisfied within a multi-criteria analysis (MCA).

Table 1: Criteria and indicators within the MCA (Ellis et al., 2011)

Criteria (Areas of Concern)	Indicators
Technical	Flood Control
	Pollution Control
	System Adaptability
Environmental	Receiving Water Volume Impact
	Receiving Water Quality Impact
	Ecological Impact
Operation and Maintenance	Maintenance and Servicing Requirements
	System Reliability and Durability
Social and Urban Community Benefits	Public Health and Safety Risks
	Sustainable Development
	Public/Community Information and Awareness
	Amenity and Aesthetics
Economic	Life Cycle Costs
	Financial Risk/Exposure
	Long Term Affordability
Legal and Urban Planning	Adoption Status
	Local Building and Development Issues
	Urban Stormwater Management Regulations

Ellis *et al*., (2011) accept that MCA is “not intended to be a SuDS drainage design approach and other hydraulic and water quality methodologies will need to be referred to in order to properly dimension individual SuDS devices”.

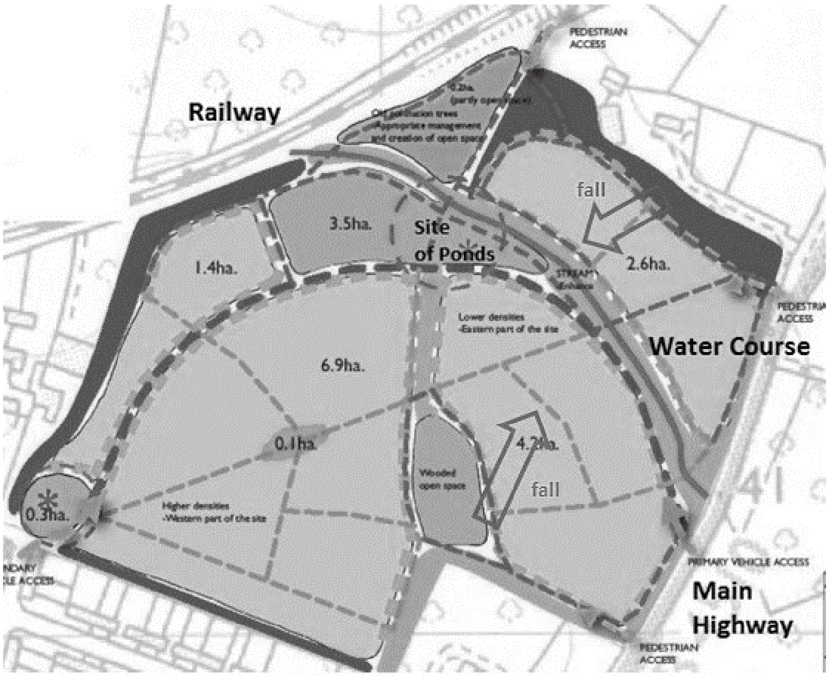
The above literature identifies the complexity of information required for SuDS, with different disciplines requiring different information and interpreting common information in different ways. This makes the practical application more difficult to apply in the real world where there are also regulations and standards.

A SUDS CASE STUDY

Case context

The case study involved the design of a drainage system for a proposed residential development located in Evesham, Warwickshire on substantially undeveloped land shown in Figure 1. A Strategic Flood Risk Assessment was unavailable but the nearest flooding was at least 3.5m below the lowest site level. The topographic survey indicated that the site fell in two directions from high points on the southern and north-east boundaries to a watercourse crossing the site. The difference in level between the highest and lowest points on the site was approximately 15.0m. The site fell into Zone 1 – Low Probability flood risk.

Figure 1, Map showing layout of site (Courtesy THDA Consultants Ltd)



Ground Investigation identified made ground up to 450mm thick or low plasticity clay up to 600mm thick under topsoil at shallow depth. This was underlain variously by gravely sand in the south of the site up to 2.0m deep, to firm-to-stiff clay in the north of the site up to 3.0m deep. Groundwater was not encountered in most boreholes. There was a minor aquifer just into the northern boundary and under a small area at the southern boundary. The site was not within an Environment Agency groundwater source protection zone, so infiltration techniques would be feasible into the gravelly sand area, dependent upon contaminant levels.

Local authority records indicated that the watercourse crossing the site was not a critical ordinary watercourse and had a catchment substantially within the development area. The average gradient of the watercourse bed was 1 in 48, for a bed width of approximately 500mm and depth between approximately 0.79 and 1.5m. The minimum distance between the top of the banks was approximately 3.8m. Hydraulic modelling showed the channel capacity to be at least 6 m3/s.

Further Hydraulic Modelling used IOH 124 (Marshall and Bayliss, 1994) to provide the greenfield run-off for 200 years at 39.1l/sec for the north area and 285l/sec. for the south area. The public highway draining to the ditch would generate run-off of approximately 80l/sec thus the ditch had considerable available capacity.

There were no local adopted sewers shown on sewer records and the nearest public surface water sewers could be utilised only by employing pumping (generally unacceptable to Water Authorities) and these would require works to increase capacity. Design criteria required that discharge from the southern section of the future development needed to be limited to 84.5l/sec and the northern section to 11.6l/sec. Modelling indicated that the total surface water discharge generated by the proposed development for the worst case 100 year plus 30% storm (EA climate change allowance) would be approximately 1400l/sec if road and roof areas over impermeable strata contribute to the flow.

Drainage strategy

The strategy was based on approximately 470 dwellings in the southern part. Of these, 322 with drives or parking spaces would be outside the area to be drained using infiltration techniques. A variety of SuDS methods could be utilised. House soakaways, permeable paving and infiltration strips would be used outside the adoptable highway to utilise the higher permeability areas. A 185mm thick sub-base with a 30% voids ratio would provide the required attenuation storage. The remainder of the site would have a piped network draining via ponds to an attenuated discharge.

The total impermeable area of land south of the watercourse is 6.7Ha. Post development run-off rates for the north and south drainage systems were modelled for storms of 1, 2, 30 and 100 years plus 30% to account for climate change. Pond modelling confirmed that the hydrobrake outflow would never exceed the limiting discharge. Due to ground levels and space a cascaded pond system was proposed in an area which could be offered as Public Open Space. Thus, the ponds would be adopted by the local authority as part of the Open Space. Modelling indicated that drainage systems would not flood for storms up to 30 years in compliance with requirements for adoptable drainage systems. The 100year + 30% storm would cause upstream flooding for the worst case storm of 252 cu m distributed across the development. This flood storage would be provided by swales, voided sub-base and/or filter strips in private areas. In cases of blockage water would gravitate to the watercourse.

DISCUSSION

The Nature of SuDS modelling

The design situation is multi-layered at different scales, multi stakeholder and multi-knowledged. The case study shows the different uses of knowledge and this can be explored using Mingers (2008) categories: propositional, experiential, performative and epistemological. The complexity and inter-disciplinary nature of SuDS design involves many assumptions, which limits model representativeness. Given this indeterminacy and the many different stakeholder perspectives means that the basic approach is Performative. That is practitioners work in a negotiative environment of decision making based on the expectations of their roles. Thus, civil engineers provide the hydrological input, landscape architects the landscape form and planting input, the planners the regulatory and consultative input and agencies argue for more environmental resilient work. This is supported by the experiential nature of much of the knowledge meaning individuals having a great sway in decisions. In this professionals know what works because they have done it before. They use epistemological knowledge from models but only to interrogate situations and to validate decisions already made. These decisions become Propositional knowledge over time and can be embedded in codes, regulations and toolkits. Thus Kirkham and Rayner's (2007) can state that "SuDS design has traditionally been simplistic, using basic equations and 'rules of thumb' often leading to conservative designs".

The information required to satisfy the criteria for a SuDS decision support is in numerous forms; some numerical, others textual and still others diagrammatic. Further SuDS design involves the detailed involvement of different disciplines who see the nature and use of models differently. Voordijk (2008) acknowledges this more generally for the built environment, by placing knowledge in three disciplines - sciences, humanities and design. Each of these is operational within the SuDS design situation. Different disciplines use this information differently each with their own evaluation and effectively own model. The scientific and epistemological models of the engineers are contrasted to the Humanities and propositional models of the planners. Paolisso *et al*., (2013) identify that humanities models are to improve dialogue, create policies and generate (environmental in this case) solutions. Thus, part of the differences is the way each discipline views models.

Set within this complexity there are different qualities of information and a difficulty in assessing what that quality is. In the multi stakeholder environment these are viewed differently and seen with different risks. The engineer is producing an answer within this i.e. performative knowledge, which is convincing to the environment agency and the client set within industry norms and standards. They are concerned that if the design was audited (or challenged later) it would stand up to a duty of care analysis based on norms. In order to undertake this, the engineer has a design path that develops as information is transformed to usable knowledge as it is accessed, created and assessed. This starts from early information accessed from library sources and local knowledge. Designers are aware that this could be of low and variable quality and this is factored into the decisions about what other information to seek (e.g. site investigations) and even what solutions are viable. Site investigations cost money and doing more may not be valuable as they only sample the ground formation; it is experiential knowledge that requests greater density in identified sensitive areas where if there was an error, there are large implications. There is still the possibility of not detecting an underground feature which alters the performance of the landscape from that expected. Questions then arise of priorities and risks which again must be modified by costs of solutions, multiple benefits and stakeholder views.

Contrasting SuDS and BIM led infrastructure information modelling

This understanding is not considered within BIM led Infrastructure Information Modelling. Again using Mingers (2008) categories, the BIM view is driven by Epistemological knowledge where the model substantively represents reality. It is this modelled reality which becomes the Propositional knowledge based on a discourse of accuracy and optimisation. Thus it is the modelling that is Performative in BIM and different disciplines are expected to share experiences of the model world. This leads to the Experiential being about the operation of models. In BIM then it is the accuracy of the data that is key and this data is fundamentally tied to geometric forms. In buildings, particularly new buildings, it is possible to place the geometry with as much accuracy as is needed and engineering concepts of tolerances become critical.

In a natural real world situation, that SuDS works in, such notions of accuracy, complete knowledge and control of the situation are fundamentally not available. The world of SuDS design is basically an empirical experiential world. The number of variables and the dynamic nature of these make the modelling problem extremely complex. In currently practice, models are used for designers to understand a situation rather than to solve the design problem. One of the key issues is that as models become more complex they have a greater demand for input information; thus, although they may be more accurate and represent more factors, they require more assumptions and a greater quantity of input data. The variability of the quality of input data limits the validity of the model and the ability to trust the output data. It also makes it much more difficult to validate the model using measured data from live situations. It is also the case in SuDS modelling that input parameters must be estimated for extreme conditions not just average conditions thus removing the ability to cancel out data noise and errors. This variability is often dealt with statistically but for the designer it is the exceptional situation that must be considered.

The Needs for new SuDS modelling

The term 'model' is used regularly throughout the construction industry but it is seldom acknowledged that there are differences in its use with implications that are rarely explored. The term has been commandeered by the BIM movement who demand a single authoritative view featuring a comprehensive integrated model accessing data from a common data environment. However, the key issue is expressed often by SuDS practitioners, e.g. Kirkham and Rayner (2007), 'models are simplified systems that represent real systems'. The word "simplified" is significant, and it is the reduction in complexity that makes models operable but this limits their representativeness of real worlds. Thus, it is important to recognise that models contain idealizations, simplifications, approximations, and fictional entities such that they can be rendered "hopelessly inaccurate" Knuuttila (2011). This is particularly the case with SuDS where it is the differences in the quality of information and the differences in the way people see information that needs to be supported.

The nature of the SuDS modelling situation is not the same as BIM as it is based on natural systems. There are no fixed reference objects to base parametric data on and the features do not connect together in a way like geometry. Global Information System (GIS) representations provide a gross view of a situation with a very grainy topography. In addition, there is a graininess about the distribution of soil types where for SuDS it is the interaction of soil types and other physical features that create water flow paths and different conditions of storage. This is made worse by the situation being dynamic. There are different time periods, important in different situations with long term changes dictating changes in rivers whereas in floods short term changes in conditions (such as a tree blocking a drainage channel) which dictate the changes in the developing situation. This requires a variety of models and each with different possibilities for interpretation. The various possible time perspectives are seen with different importance to each profession. Even for the civil engineer the difference between long term hydrological management is contrasted by the short term consequences of extreme weather events. Similarly, the landscape architects understanding of the long term control of soil water through landscape and planting features is contrasted by the engineers' desire for short term predictability of water movement. Placing this complexity against a decision about how much to spend on a SuDS scheme, and how much risk that might be acceptable, can only be handled through a collective value judgement at the point of decision making.

We are left then recognising that a comprehensive integrated model for SuDS is not possible and even a common data environment has in-built problems. SuDS requires a multi model environment with the models being decision support tools for an inter-disciplinary team. The indeterminate nature of much of the information is handled by developing decisions progressively rather than seeking all the information from which a solution is calculated; information and knowledge are co-produced. Modelling tools can be improved to undertake this but this needs to be driven by the need for collective comprehension and communications rather than for individual accuracy and comprehensiveness. This has learning for BIM situations as they also contain many natural situations which do not yield to modelling in the way BIM assumes. There is a temptation to force situation to be like the model rather than to create models that better represent situations. This understanding drives us to see SuDS models differently basically as decision support tools.

CONCLUSIONS

The demands in our modern world for infrastructure certainty and for environmental responsibility, within budget constraints, drive modern design and development approaches. This drive is pressurising us to believe that the whole process can be solved by computer software models so long as they are written correctly. There seems also to be a belief that all knowledge related to a problem can be identified and that choices and decisions can therefore be substantially automated. As this paper has shown, models for SuDS can exist only to support decision making and even these are subject to multiple assumptions and approximations in the parameters that they can employ. These differences are not acknowledged in current infrastructure information modelling which seeks to automate the process in a single comprehensive model. In conclusion, it is recommended that; more work needs to be done revealing the use of knowledge in SuDS design case studies; new models need to be created for natural systems that can utilise different input information qualities and perspectives; and models need to allow a more interactive design between stakeholders.

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