DYNAMIC HUMAN COMPUTER INTERACTION (HCI) AND GIS IN THE DESIGN OF WATER COLLECTION SYSTEMS AND OTHER LAND USE RELATED ISSUES

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ABSTRACT

This paper explores the feasibility of implementing on GIS platforms Dynamic Human Computer Interaction (DHCI) processes for the production of a feasible solution to a land related problem. Data flow diagrams provide the methodological framework to identify the type of HCI best suited for a given sequences of operations. Two use cases, land parcels reallocation and hydraulic design of storm sewer, show that Dynamic HCI is feasible using the current GIS technology.

KEY WORDS

human-computer interaction, decision support, system design.

INTRODUCTION

Land-use related projects are open problems, as decision-makers generate feasible alternatives to eventually select one of them, normally in a multicriteria decision framework. Selecting a corridor for a new transportation infrastructure, reallocating land parcels and laying-out and sizing a storm water collection system are examples of open problems. While various strategies may be followed to generate and evaluate alternatives, a typical process adopted by experienced professionals starts with an initial solution that is successively and dynamically modified. This is a very creative activity where the user sits in the pilot seat, integrating to his decision process the information the assessment of the current solution provides.

This process can greatly benefit from the implementation of human computer interaction (HCI) processes acting dynamically on the spatial entities managed in a GIS. This paper investigates creative HCI for the production of land related management alternatives. It first describes the types of HCI and their principal characteristics as an aid to identify the HCI best suited to land management related studies. Data Flow Diagrams (DFD) of the process are developed to identify where HCI can best be implemented in a given decision-making process. Two applications, land parcels reallocation and sizing of storm sewer pipes serve to illustrate the methodology, to address implemention aspects and to discuss their feasibility.

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HCI AND DHCI

It is useful to differentiate among HCI processes as any instructions given to the computer and any results sent back to the user fall within HCI. It is also useful to address a basic classification of HCI because the name is still widely dedicated to the development, by cognitive and software engineers, of easily understood graphical communication screens (interfaces) and of easily followed paths between these hierarchical graphical windows.

- A well known HCI is the Bancomat. Through the graphical interface, the user instructs the computer to execute the banking operations he wants to complete and receives a feed-back on the feasibility of the operations or obtain the results of the operations. It is a simple graphic interface with predetermined operations and results. There is no room for creative use of the interface as the objective is to establish a simple dialogue between the client and the computer. The interface serves to pilot the operations which are well defined, normally well understood by the user and in limited number.
- HCI are present in the user-friendly preprocessing of input data to and in the control of computational software like those found in many engineering applications – numerical simulation of complex processes and linear and non linear optimization of large and complex systems. They are also present in the post-processing of the numerical results providing options for tabular and graphic representations. HCI, as for the Bancomat, provide the communications channels between the users and the computer. Even though the development of these interfaces is often a complex activity due to the number of options the software provides and to the number of hierarchical levels where the user may interact with the computer, these interfaces pursue the objective of controlling the computer in its execution of the operations (or sequences of operations) the user selects in a given situation. There is little room for creativity as these computer tools have a well-defined structure and perform computational tasks with few (if any) degrees of freedom once the problem is defined through the input data.
- HCI are present in computer platforms like the Microsoft Office packages. They provide the communication channels to activate functionalities the software makes available to the user as he creates his text, designs his presentation, develops a computational sheet or structures a data bank. HCI of this type are found in basic GIS platforms, the functionalities provided for the input, retrieval and management of the data, for the production of thematic data and for the cartographic representation of spatially related information. These interfaces put very little constraints on the creativity of the user as the platform remains a computerized aid facilitating the execution of a creative activity like writing a paper or a report. But the HCI in these platforms do not provide any valuable feed-back to assess the quality and pertinence of the current solution or work produced.

- Dynamic HCI (DHCI) refer to interfaces between the user and the computer, where the feed-back from the computer is essential to the task the user performs. In addition to the communication channels the interfaces provide, DHCI allow the user to receive, in real-time, information that he integrates based on his expertise and experience to modify the current status of the work under way. DHCI do not constrain the creativity of the user within the feasibility framework of the particular field involved while providing in feedback the magnitude of the evaluation criteria adopted for the problem.

This paper explores the nature, the implementation and the feasibility of DHCI as an aid to generate alternative solutions to land-related problems. They are essential components of the exchange of information for controlling a creative process in constant evolution in response to the magnitude of performance indicators. The DHCI are implemented on a GIS platform for the generation of alternatives to a land parcels reallocation process (use case 1) and to the hydraulic design of storm sewers (use case 2). The next section addresses methodological considerations applicable to the design of DHCI in land related problems, illustrated by the two applications selected.

USE CASE 1 : LAND PARCELS REALLOCATION

Land-parcels reallocation is realized within a well defined zone, whose parcels' structure is found to be inadequate for agricultural or building purposes (parcels usually too small due to a long history of subdividing for inheritance). The most current purpose of reallocation is to reshape the whole zone and to redefine new land parcels, so that each owner gets well shaped new parcels, for approximately the same value as he had in the former structure. Land parcels reallocation unveils as a very relevant use case for DHCI studies because of its very high legal and operational formalization level that facilitates the requirements definition. It was presented in a former paper (Golay et al. 2000) that this use case is taken from.

The most relevant reallocation criterion is the land value, that is usually established as a polygonal network by qualified experts, taking into account the soil quality, the parcel location, etc. Due to the complexity of the reallocation and reshaping requirements, there is currently no computer tool able to propose satisfying, automatically generated solutions to this problem. Thus, the engineer has to take on the added responsibility of identifying satisfying solutions from his own creativity. Based on his own experience, he usually applies heuristics, trying to successively define parcels for each participating landowner, and to adjust the boundaries of the new parcels according to the owner's financial claims. Once he has determined an approximate solution, the engineer can use software tools like "polygon overlay" to compute the exact value of each new parcel and calculate a "rest" value that will be paid to or by each owner. This process is represented by the Data Flow Diagram[3] (DFD) on figure 1.

[3] A Data Flow Diagram (DFD) (Gane and Sarson 1979) is a graphic representation linking, on a systemic basis, processes to data stores through data flows. The DFD describes the information (data, constraints) required for a given treatment, its outputs and the sequence of tasks to be performed.

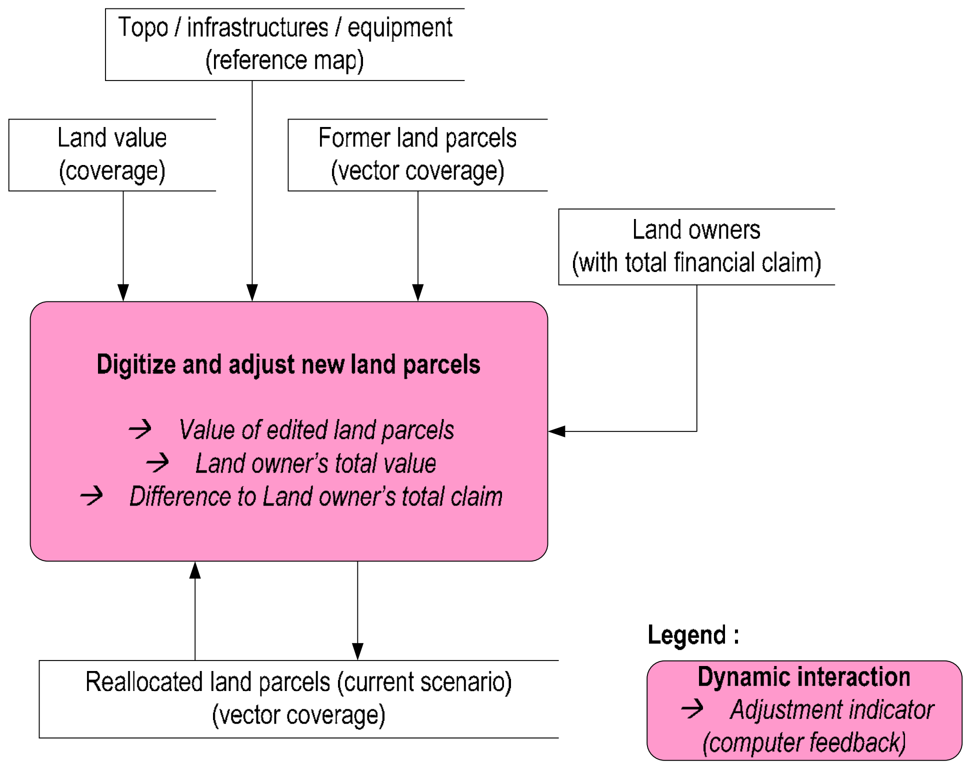

Figure 1: DFD of the parcel delimitation and attribution process.

Some of the individual processes do not rely on relevant DCHI: they are either deeply structured operations where user's creativity is not at stake, or purely heuristic actions beyond computer support capabilities. But the parcel delimitation and attribution process matches the Dynamic HCI characteristics described in the former chapter on "HCI and DHCI". It deserves therefore more attention.

The concept of an interactive platform that allows engineers to get real-time, aggregate values of a continuously defined spatial variable (for example, land value) within structures he is reshaping, e.g., bi-dimensional objects as land parcels, seems to be very relevant to support engineers in their search for satisfactory restructuring scenarios (see figure 2). An engineer must be able to change the shape of a parcel and to process rapidly (ideally real-time) information on its current value, until he can be satisfied by the achieved result. In figure 2, after each mouse move of a parcels corner or limit, the operator gets back from the computer the actual value of the new parcels computed from the soil values (rasterized background), the aggregated land value allocated to each involved parcel owner, and the corresponding owner's financial claim. This should facilitate the elaboration and the assessment of several alternatives within a fairly short time, thus making the search for satisfactory solutions easier and more efficient.

In order to better identify processes with high dynamic interaction potential on DFDs, we suggest to highlight these processes (see for example figure 1) and to clearly mention the name of the dynamic interaction and the feedback values interactively returned by the computer (in italics in figure 1).

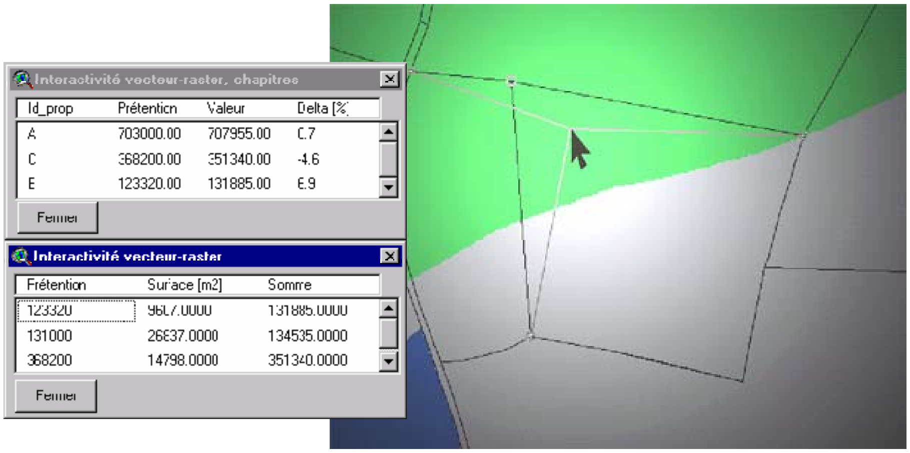

Figure 2: DHCI prototype for land parcels reshaping.

The suggested dynamic interactions should dispatch tedious, repetitive, and time consuming tasks to the computer, allowing engineers to focus on more creative engineering tasks, also facilitating what (Cartwright 2004) calls "engineered serendipity". This reinforced interactivity is also a great opportunity to transform today's GIS into true design support systems.

USE CASE 2: HYDRAULIC DESIGN OF STORM SEWER

This second application explores the feasibility of DHCI in the design of storm gravitary sewers. The objective is to select a network of pipes and to determine the diameter and the slope of each pipe. The inputs are the topography of the urbanized area, its land use both in terms of size and location of the parcels (ERA: elementary runoff area) and of the impervious and pervious surfaces. Their runoff coefficients are estimated by the user based on their land-use, shape and runoff slope. A list of commercial pipes, minimum and maximum water velocities applicable to each type of sewer pipe, best practice rules and characteristics of the local rainfall process, often given by intensity-duration-frequency (IDF) curves, complete the basic information the urban hydrologist relies upon. For this application, the design is based on the Rational Method (Brière 2000; Mays 2004) adapted for small storm sewer network with no temporary detention provided.

The design process begins by the determination of the drainage basin that includes in part or totally the area to be equipped and the creation of a pipe network that collect storm water by gravity. An initial schematic pipe network is proposed based upon the future (developed) soil elevations. The user then aggregates into a runoff unit (RUj) the basin's sub-area whose water flows into node j of the proposed pipe network. An RUj is limited normally to a few hectares (ha) and is characterized by its size, average surface runoff slope, percentage of imperviousness and runoff coefficient, the latter being a weighed average of the runoff coefficient of the ERAs included in the RUj. Starting at upstream nodes, the hydrologist estimates the time of concentration of the contributing RUj to node j, determines the time of concentration of the total area contributing runoff to node j, the storm intensity from the IDF curves and the maximum flow, QMAXj. The hydrologist then selects a commercial pipe diameter D_j and slope, S_0. A feed-back is provided here to the designer for him to check if the water velocity is within the admissible range and to decide if another pipe slope can be a better choice, considering the network and the topography of the basin.

Because of the deeper complexity of this second use case, it is necessary to model it with two imbricated DFDs. Figure 3 presents an overall DFD (DFD-level 1) of this use case, discretizing processes as independent as possible from an hydrologist's expertise. Each action identified shows the input, the global treatment of information to be carried-on and the information generated. For instance, *Delineate Catchment* defines the drainage basin at the outlet node of the area to be equipped, either traced interactively by the hydrologist or alternatively defined by a GIS software if this functionality is available. *Delineate Elementary Runoff Area* (ERA) *and set parameters* and *Sketch pipe network empirically* input numerical data. *Delineate RU and set parameters* identifies an RU and delineates its sub-basin. The computer then computes the resulting runoff coefficient by overlaying it with the intersecting ERAs. *Compute and adjust pipe parameters* determines the flow variable of this RU_j and the diameter and slope of the pipe with its upstream node at node j.

However, potential dynamic interactions cannot yet be identified on the too general overall DFD level-1. They can only be approached through a more detailed modeling of each global process (DFDs level-2). Figure 4 shows for instance the DFD level-2 developing the level-1 process *Delineate RU and set parameters*. At any node j, the water contributing sub-basins are identified, their respective time of concentration retrieved for future use. Dynamic interaction is first centered on the user selection of a potential location of a downstream node referred to node j+1 (DI #1). This node is adjusted so that its upstream sub-basin encompasses a relevant surface of the overall basin; for each interactively considered position of node j+1, the computer shows then in real time the upstream natural, automatically computable sub-basin. The node j+1 final location and its computed natural sub-basin are then used in a second step (DI #2) by the hydrologist to digitize and adjust the boundaries of the corresponding runoff unit RU_{j+1}, taking in account future flow rerouting due to new equipments and constructions. This action goes on until the user is satisfied by the current location of node j+1, on the basis of the size, shape and representative slope of the resulting RU. Then the hydrologist defines a representative surface overland flow length (DI#3) that will be used to compute the time of concentration of the RU_j. Interactive adjustment parameter is the resulting time of concentration.

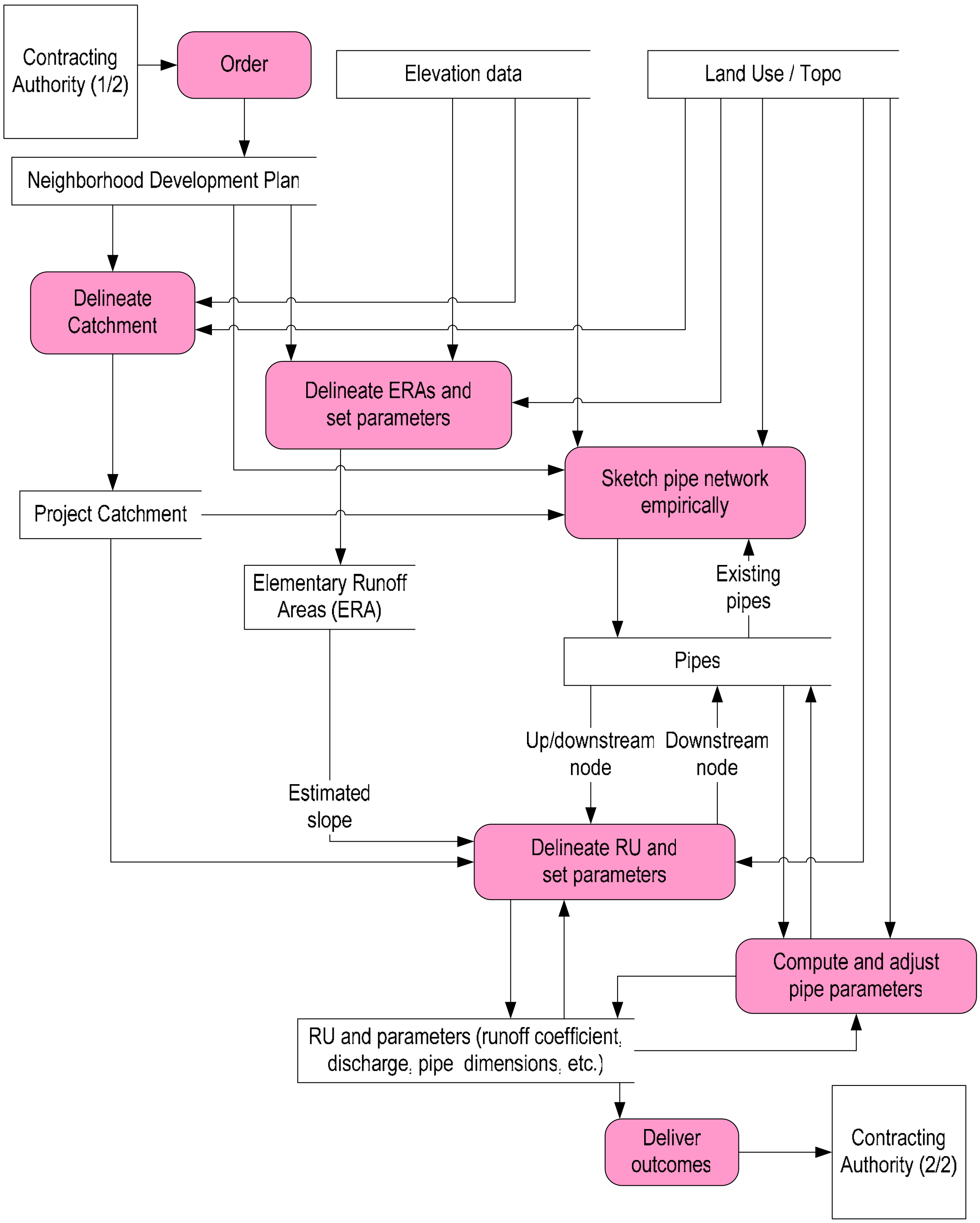

Figure 3: Overall DFD of the use case 2 “Hydraulic design of storm water sewer”.

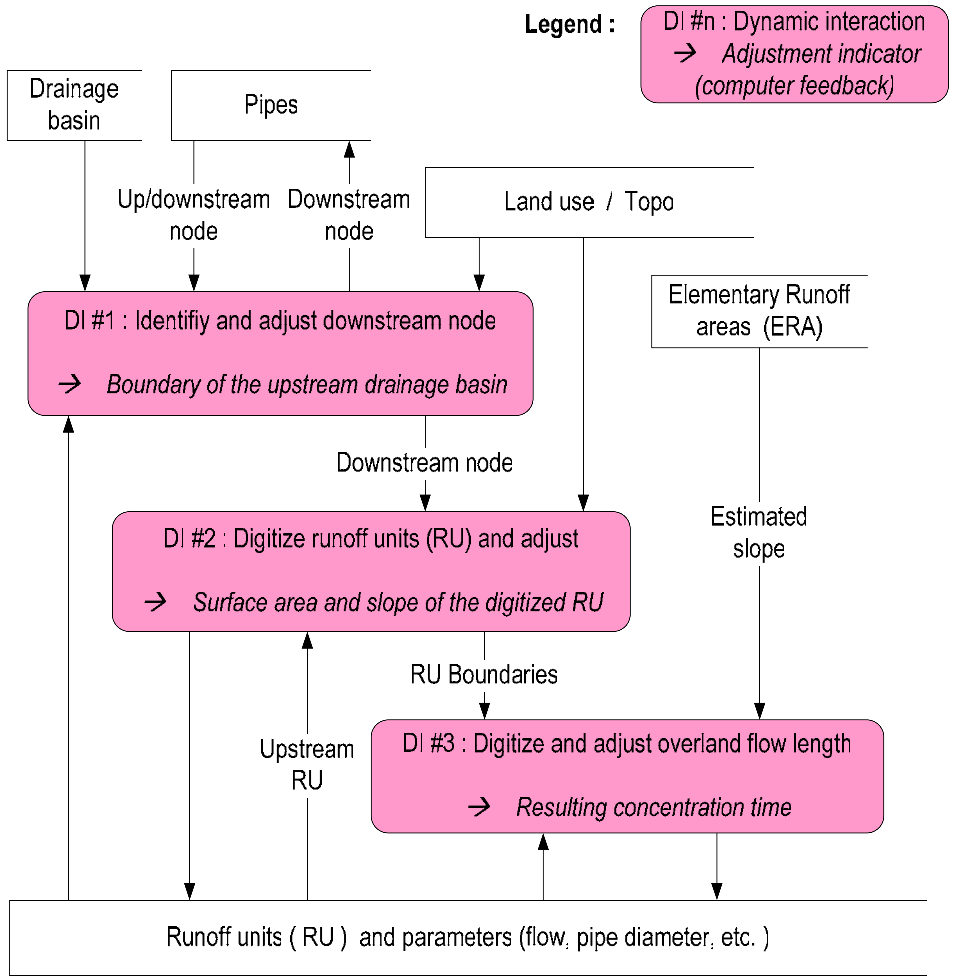

Figure 4: DFD level-2 of the global process "*Delineate RU and set parameters*"

A DFD level-2 has to be defined for each level-1 global process. Every sub-process should then be characterized by a type of interaction according to our former section on "HCI and DHCI". However, neither strongly structured "Bancomat-like" actions nor purely creative "drawing-like" actions are of high interest to us, because many examples of relevant software already exist on the market. But creative tasks, relying on the engineer's ability to develop innovative solutions within a highly constraining environment, could very much benefit from new dynamic human-computer interaction concepts and tools. Our first use case on land parcels reallocation showed that (relatively) simple GIS functions such as vector-raster overlay operations can be very supportive. On the other hand, our second use case on hydraulic design of a sewer network showed that more complex functions such as automatic basin delineation could be of high interest to support Dynamic HCI, as long as they can be used in a "real time" interactive adjustment process.

CONCLUSIONS

Even though many ways exist to generate alternative solutions to a land-related problem, one frequently adopted is the gradual improvement of an initial solution. This paper explored dynamic HCI in support of the design process, which often implies many time consuming, tedious heuristic tasks, reducing the time the engineers can allocate to the development and comparison of several solutions. Dynamic HCI actions provide the designer with a real-time feed-back on the current solution as he searches for a satisfactory if not optimal solution to a particular problem. They have the potential to complete many repetitive and time consuming computations required to assess changes to the current solution. The exploration conducted and reported in this paper shows that dynamic HCI is feasible using the current GIS technology. In the two use cases, the interactions between the user and the computer are occurring in real time, providing an assessment of the proposed modification to the current solution.

The methodology proposed for the development of dynamic HCI applies DFD to translate the design procedure into a sequence of actions at the first level (level-1), and to identify the HCI best suited to the action to be executed. The level-2 DFD develops the dynamic HCI.

Dynamic HCI provides very useful support to the design process of water collection systems and to the analysis of other land use related issues. The next phase of this exploration will focus on the definition of an interaction typology and on the development of attractive prototypes using more complex computer simulation models to address the trade-off issue between the feed-back time of response and the quality of the information sent back to the user.

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