Environmental feedback in an iterative design process

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Abstract

This paper is an account of a practice-led project carried out during an "architects' residence" in Kielder in the North of the UK, between 2003-2006. It describes how a systems-based approach was applied to cycle through the design-process iteratively. The aim was to fabricate an object embodying a mechanical mechanism that would visibly respond to the diurnal cycle of environmental change found in microclimates in Kielder. An evaluation of the object's behaviour was carried out based on environmental metrics. The iterative process of building and monitoring prototypes suggests a design methodology that incorporates "as-built and operated" evidence into the design process.

Initially, the design of the object was investigated using virtual models that served as descriptions of the finished object due to be placed on sites in Kielder. In an iterative approach to design with physically fabricated prototypes, there is the opportunity to capture and use feedback to develop the design and location of a prototype in the subsequent iteration. This paper discusses the methodology implemented in a case-study project and how information returning across the real-to-virtual threshold became design intelligence used in the next iteration. The collection of empirical data by "design probes" [Sheil and Leung, 2005] was coupled with a computer simulation; two feedback loops were identified, one informing model validation the other, objective validation. An iterative methodology is proposed to revise objectives, to re-model solutions, to re-synthesise outcomes and to re-locate on-site between iterations based on feedback from the 'as-built and operated' data.

KEYWORDS : Data-driven modelling, design-process, passive-actuation, responsive system

Introduction

The design research group Sixteen*(makers) have explored digital design and its relationship with digital fabrication through a series of projects including "Shorting the Automation Circuit" (StAC) (Ayres, 2006). The StAC project developed the design of an object using solid modelling CAD software, data was exported and used to fabricate a physical prototype that was then placed in an unused observatory on the UCL campus. The fabricated object was partially exposed to the external environment and the effects of wind direction and magnitude were digitised using sensors and microprocessors embedded within the object, these were interfaced to a PC to "record an informal 'thumbprint' of the prevailing physical conditions". Following StAC and complementary projects Sixteen*(makers) were invited to an "architects' residence" in 2003 by the curator Peter Sharpe at the Art and Architecture Partnership in Kielder (AAP@K). An "architects' residence" as distinct from an architect's "commission" offered the opportunity of an open brief, a long time-scale and the expansive (62,000ha) territory of Kielder's forest and reservoir. The StAC project produced one object collecting environmental data that suggested changes to its form in a "search for specificity" p. 80 Callicott [2001], the "architects' residence" in Kielder has produced a series of objects in successive iterations, a brief description of the stages of each iteration are given below, followed by a presentation of the case-study itself, finally there is a discussion of the advantages of this methodology.

An Iterative design-process

An iterative design-process is suggested here as an approach to design practice with the following initial stages:

1. A definition of objectives and operating characteristics (the statement of requirements)
2. A definition of performance metrics (measures to assess the realisation of the objectives)
   Followed by a cycle of steps to:
3. Describe design intent (design documents, digital modelling and simulations) and provide instructions to manufacture, assemble and locate (exported from digital models)
4. Synthesise (fabricate, assemble and site a physical prototype)
5. Observe (digitally capture site-specific 'as-built and operated' behaviour)

This is illustrated in figure 1, beginning with a declaration of (1) and a selection of (2) the first pass through (3) to (5) establishes a design outcome crossing from the virtual to the real. The need for and relevance of (5) to the case-study presented here is reflected in a survey of adaptive kinetic architecture that identified the limited availability of empirical information of the performance of existing systems and how it is necessary for the design and engineering of a kinetic architecture to have accurate models and realistic input values to the parameters that drive their behaviour, while also providing a means for their validation [Sanchez-del Valle, 2005]. An iterative design process has similarities with evolutionary strategies that use simulation to evaluate behaviour, behavioural deviations between as-simulated and as-operated may be accounted for by the completeness and accuracy of the virtual simulation environment and uncertainty in the input values it uses as well as tolerances in metrology from sensor measurements of the physical environment [Jakobi et al., 1995] and chapter 3 in [M. and Godfried, 2003]. The case study has an output control element with a passive-response to its environment, therefore the discussion here is restricted to how the model description and its simulation of the environment was informed through feedback.

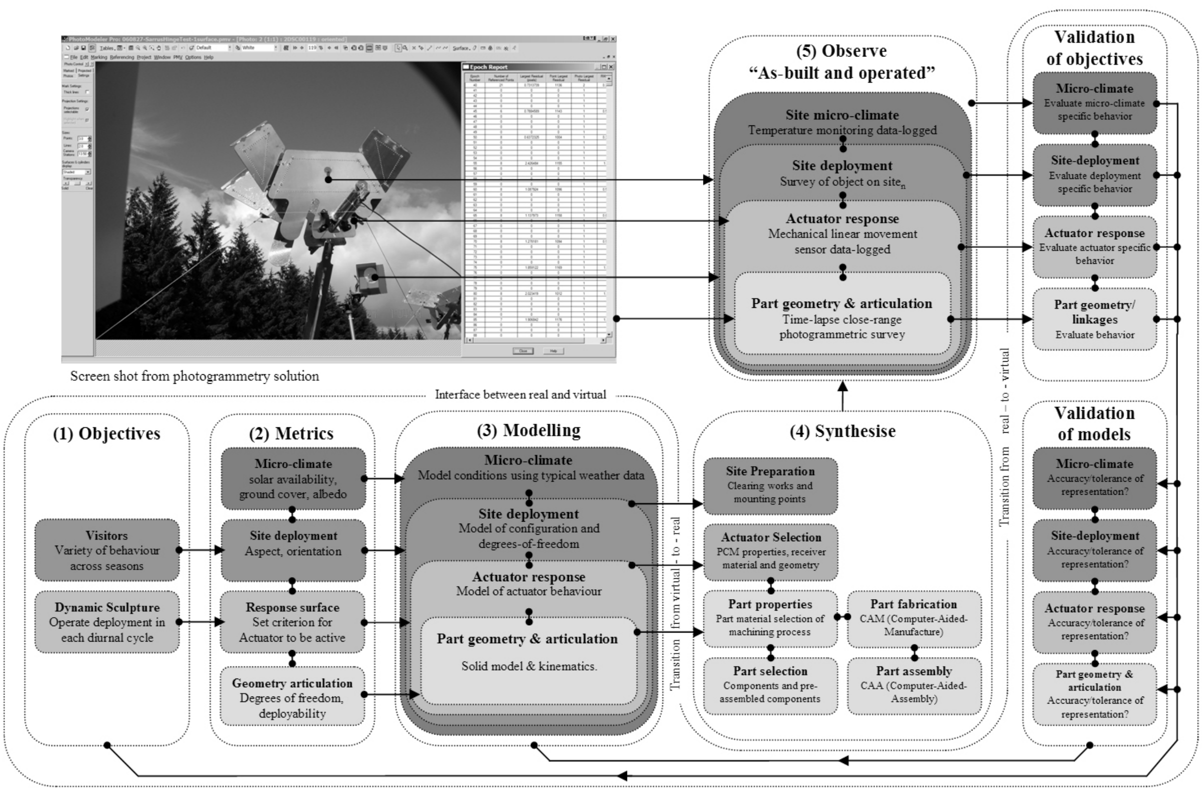

Figure 1: System diagram for an iterative design-process

Kielder Forest

The case-study is a dynamic sculpture that was designed to change its shape between dawn and dusk in response to its local micro-climatic environment. The geometry of the sculpture's articulation is complex, for which a system was designed to capture its transformation in between a deployed and stowed configuration to understand its dynamic nature. In order to study the response of the sculpture's to its specific site, environmental micro-climate data was gathered and combined with geometric data in an animated visualisation. Kielder forest experiences a cool northern temperate macro-climate (Latitude 55°) and is a managed *[sic artificial]* forest planted in the expansive Cheviot Hills. The hill and valley meso-climate can experience rapidly changing weather conditions and within the large territory of the forest the variety of microclimates range from exposed windswept hilltops to sheltered hollows deep within the forest coupes.

Site Micro-Climate Selection

A site was selected in a forest clearing at the junction of three forest coupes with different plantation dates with unobstructed views to the east and south and varied shelter to the north and north-west. It was anticipated that this would expose the observation site to a variety of weather conditions and that the micro-climate would change as each adjacent forest coupe reaches maturity and is harvested. Although Kielder forest is one of the most remote locations in the UK, it is a popular day-trip destination in the north-east attracting an estimated 230,000 visitors per year[1]. The artificial wilderness forms the physical and visual context for an audience to contemplate this sculpture.

The Design Objective

The requirement was to animate the sculpture given the cool temperate thermal conditions and remoteness of the Kielder forest. The design of the mechanism and form of the sculpture together with its site aspect, orientation and exposure in a given micro-climate were to display a varied behaviour for the visitor at different times of the day and over the changing seasons.

Passive Actuation

The remoteness of the site motivates an environmental imperative to design the sculpture and its observation system for self-sufficiency, autonomous control and low-energy use. To achieve dynamic movement in this environment it was proposed to use a passive temperature activated actuator containing a phase-change material (PCM) as the hydraulic medium. The hydraulic behaviour of this actuator is determined by net heat gains and losses, net heat gains cause the actuator to warm and if sufficient reach its critical-point and melt, it expands considerably extending the actuator and this transforms the sculpture to a deployed configuration (see figure 4. Sufficient net losses causes the PCM to freeze thus contracting the actuator aided by a return gas-spring, this transforms the sculpture back to a stowed configuration (see figure 3. A standard proprietary actuator was used containing a mineral wax with a melt temperature of approximately 25 degrees C. A typical late-summer day is shown in figure 2 indicating the diurnal time-temperature time-series during daylight hours, the time-series plots solar-radiation, solar heated air (actuator surface temperature) and the linear mechanical movement of the actuator. The plot of actuator expansion shows a single 'camel-back' indicating a melting/freezing cycle during which the sculpture transformed from stowed to deployed and returned to the stowed configuration at dusk.

Environmental Responsive

A very simplified model of temperature/actuator response was used for the first iterations using a linear and proportional relationship between temperature and actuation. The case-study attempts to establish a base-set of parameters to describe the physical environment that will be responded to, consisting of those parameters that theoretically have the most effect on the sculpture's behaviour: solar-availability was assessed by an elevation survey, the site-specific thermal micro-climate was monitored at three candidate locations at thirty minute intervals for one year to provide a realistic input data-set for the simulation. During a five day pilot trial of iteration three, tempera-

[1] http://www.artscouncil.org.uk (estimated figures for 2002)

ture, global solar radiation and linear movement of the actuator were also monitored at five minute intervals.

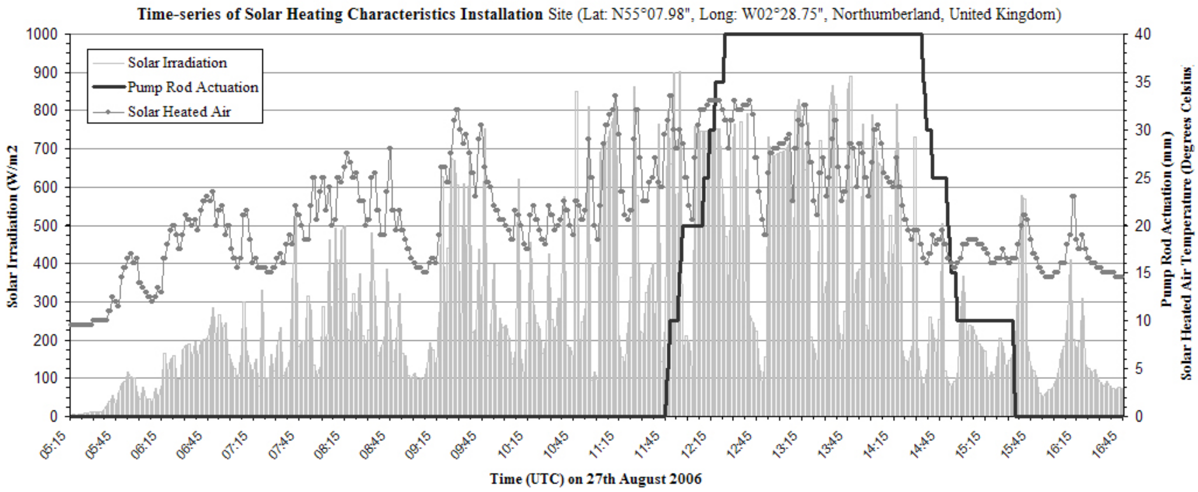

Figure 2: Sample Temperature-Acutation Time-Series

The Observational Study

Given these base-set parameters the capture of as-built and operated behaviour required spatial and temporal correspondence between environmental parameters modelled in simulation and those monitored on the real sculpture to achieve a 'base-set robust' response model after [Jakobi et al., 1995]. This was feedback that informed the validation of the response model. The geometry description of the sculpture was the framework to coordinate the environmental parameters as 'meta-data' between a CAD solid-model in the virtual and survey metrology using time-lapse close-range photogrammetry in the real "as-built and operated".

Discussion

A spatially coincident and temporally synchronised animation that composites simulated with as-built and operated provides feedback by high-lighting deviations between designed and real, whilst this feedback is descriptive and does not explain how or why a deviation exists its value is when deviations are exposed that are particularly large or unexpected. Since formal design decisions and engineering considerations to achieve the sculpture's behaviour are strongly influenced by the environmental feedback data captured from "as-operated", each cycle in the iterative design-process provides an opportunity for a prospective design to be evaluated both qualitatively and quantitatively against the performance of past designs on a given site. This feedback informed the validation of the design objectives. The case-study illustrates an implicit challenge for a passively-powered dynamic sculpture; to achieve a temporal match between the effects of an unpredictable natural energy resource *the weather* and the desire to drive a dynamic behaviour, since the passive actuator used to operate the mechanism is sensitive within narrow margins of environmental and temporal tolerance the benefit of an iterative design methodology is to support the systematic reduction of deviations between virtual simulation and actual operation through feedback.

Further Work

An engineering model that considers in more detail the heat transfers between the surrounding environment and the passive-actuator receiver over time would improve the efficacy of the model, this could support design decisions for future iterations of the dynamic sculpture designed for the Kielder forest. The data collected during this case-study provides empirical data to assist building and calibrating such a mathematical model if supported by further observational and controlled studies. A generic model suitable for behaviour modelling in different micro-climate conditions may be beneficial to design evaluations for a variety of architectural applications of passive-actuators. Given a model with greater efficacy there is the opportunity to address the challenge of achieving a temporal match between availability and need through the design and control of response modifiers e.g. dynamic insulation, solar

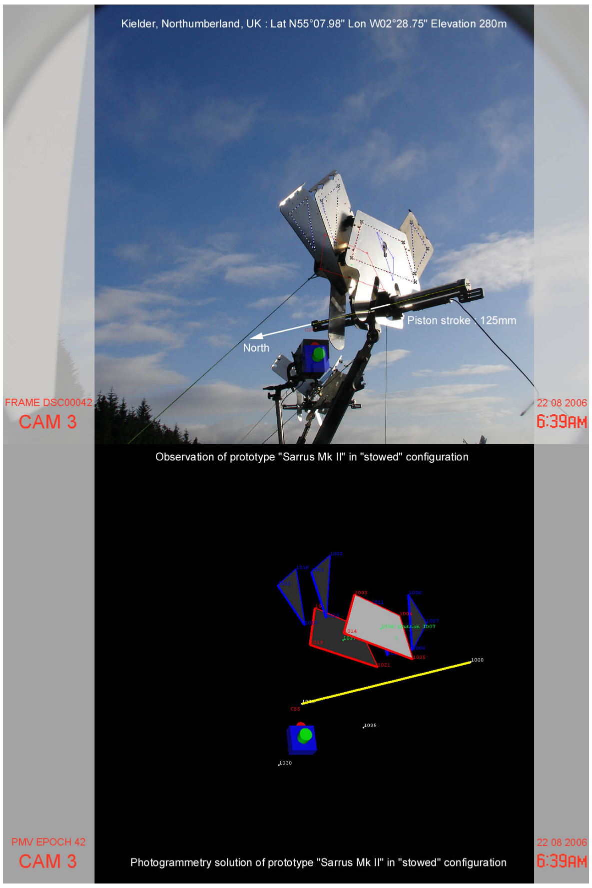

Figure 3: Sculpture stowed at 11:25hrs UTC

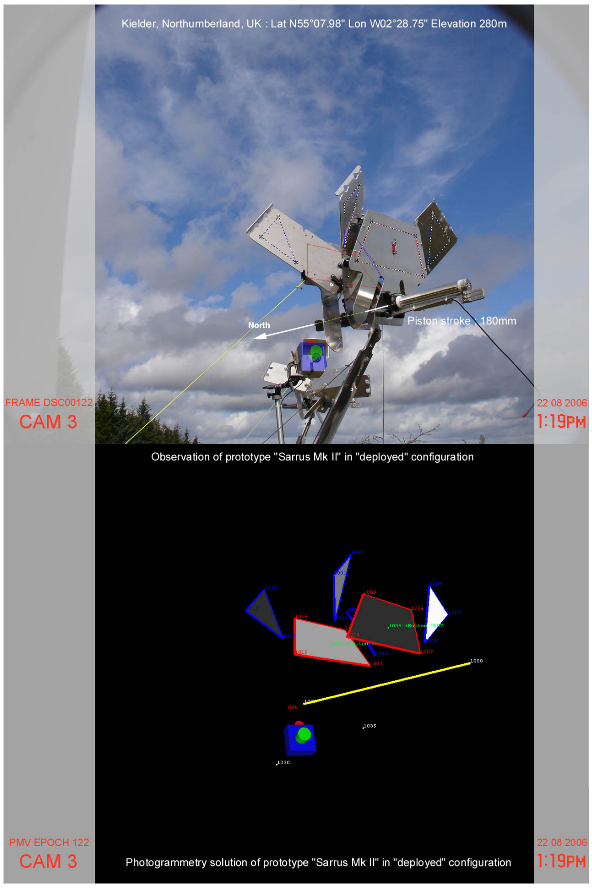

Figure 4: Sculpture deployed at 13:05hrs UTC

radiation shade or concentrators to increase or decrease the rate of heat gains and losses to meet anticipated needs. This would need the development of an intelligent control system that actively monitored the prevailing external site micro-climate while considering the possible and likely conditions for the near-future given specific performance objectives.

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