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Chapter Three

Human Factors and Ergonomics through the Lifespan

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1.0 Introduction

Designers of today’s environments face unprecedented challenges in accommodating an increasingly diverse population across characteristics of age, disability, ethnicity, gender alignment and religion to name but a few. Eliciting, and working to meet the associated population needs is achieved through the application of a Human Factors and Ergonomics (HFE) approach. This chapter will inform designers of the role of HFE within interior architecture with specific consideration of design challenges across the lifespan in promoting health and wellbeing. It will demonstrate how design can meet physical, sensory, cognitive and emotional needs over a variety of environments including: workplaces, schools, domestic settings, care homes, hospitals and transport.

2.0 Human Factors and Ergonomics in Architecture

There has been a tendency to use the term ‘Ergonomics’ to refer to interactions with the physical environment, and ‘Human Factors’ in connection with psychological and organisational issues. However, from both theoretical and professional perspectives, one cannot be considered without the other, so the
terms are now used interchangeably\textsuperscript{1, 2}. Given the wide range of interactions which people undertake within interior architecture, it is evident that each term in its own right is applicable in this context and so the term HFE will be used within this chapter.

The role of HFE is to apply a scientific approach to the design of the systems (micro and macro) in which people interact with their physical, organisational, and social environments to give the two key outcomes of optimizing human wellbeing and performance\textsuperscript{3}. Fundamental to this optimization is the need to ensure that the design of the environment and the activities within it support the needs of the users.

2.1 Defining the Environment in HFE

From an HFE perspective, the human-physical environment interface\textsuperscript{4} often overlaps with HFE domains of cognition and organization. However, the focus is often air quality, noise, illumination and vibration, or more locally, workstations, individual products, or equipment and furnishings, rather than the larger-scale concepts associated with spatial layouts or with other aspects of the system\textsuperscript{5, 6, 7, 8}. As a result of this lack of clarity, four subset “components” of the HFE environment have been drawn from the literature\textsuperscript{9}:
1) **Workspace Envelope**: the wider workplace including the building characteristics, arrangement of personal workspace components, and space constraints.

2) **Personal Workspace**: the layout of the “workstation” or immediate area of use, including the relationship of equipment, furniture, and controls available to the user (including anthropometry).

3) **Products**: the selection/specification of equipment, furniture, or controls.

4) **Ambient Environment**: the physical environment of thermal, air, noise, visual and illumination considerations.

2.2 When to Consider HFE in Design of the environment

When developing the built environment, there is acceptance that problems addressed early in design require reduced effort and expense to fix than those later in design, production or use\(^{10,11}\) and this can be especially important in the context of safety considerations\(^{12}\). Within the Safety Risk Assessment Toolkit for the Design of Healthcare Settings, a cost influence curve was developed to illustrate the impact of moving safety upstream in the design process\(^{13}\). The curve differentiates between the ability to influence the lifecycle costs of a building project through a proactive design approach as compared to a more costly process.
of retrofitting. Changes early in design are less expensive but increase in cost through construction and occupancy; the highest costs relate to the long-term impact of recurrent adverse events over the lifecycle of a building, often 30-50 years or more. Likewise, HFE efforts are better placed early in design.

2.3 Applying HFE Principles in Design

Hignett\textsuperscript{14} argues that poor design can permeate throughout the system requiring reliance on human adaptation (coping) rather than beginning with a design that does not require behavior change. This is fitting the user to the environment, rather than fitting the environment to the user\textsuperscript{15,16}. To understand fit, however, it is important to understand the active participants and general conditions of human performance, behavior, and user characteristics. For example, in considering safety in healthcare design, safety is a result of the complexity of the organization, people, and environment (SCOPE)\textsuperscript{17}. Designing with HFE principles establishes a framework to investigate complex systems relationships of the organization, people, and environment for particular outcomes such as falls\textsuperscript{18}. This can be represented as a matrix of design considerations, as shown in Table 1.
2.4 HFE Methods

A variety of methods for identifying, measuring and evaluating user requirements can be applied to ensure that key issues have been identified and resolved. It is important that user needs remain at the forefront of this iterative process with both direct user involvement and indirect representation via user data and models. Typical HFE methods include:

- **Anthropometry**: human body measurements of size, shape, strength, mobility, flexibility and working capacity\(^{19}\). This branch of HFE provides data to match the physical demands of the environment with human limitations and capabilities.

- **Hierarchical Task Analysis (HTA)**: describes a task as a higher level goal (e.g. safe transportation of medicine) with a hierarchy of subordinate task steps. At each level of the subtasks a plan is used to direct (inform) the sequence and possible variance of task steps\(^{20}\). It has been used to describe system dynamics and human-system interfaces\(^{21}\).

- **Interviews and surveys**: to obtain first-hand accounts from people about their activities and tasks during daily life\(^{22}\). This includes knowledge elicitation from domain experts\(^{23}\) as well as participant (user) involvement in HCD\(^{24}\).
• *Link analysis*: uses observations to collect data about the interactions between components in a system (task activities and physical/cognitive relationships) to provide outputs as spatial diagrams\(^{25}\).

• *Empathic modelling*: where designers engage with a simulation device to help understand the user's perspective in the outside world e.g. to use a wheelchair for a day\(^{26}\). This method has been used in architectural projects and is taught in architectural programmes within HFE modules\(^ {27}\).

• *User trials*: are often used with detailed scenarios (based on task analysis) within a simulated environment (mock up) to allow a systematic evaluation of the design under controlled conditions\(^{28}\).

• *Design Decision Groups*: a participatory HFE approach which combines several methods including word map, round-robin questionnaires, layout modelling, silent drawing and mock-ups. This systematic approach is used for workplace layout and design to create shared experience events\(^{29}\).

3.0 HFE examples across the Lifespan

A number of case studies across the life span are presented to demonstrate the embodiment of the HFE approach in the design of interior architecture for health and wellbeing. A range of human characteristics are addressed, HFE methods illustrated, and domain applications showcased.
3.1 Early life

3.1.1 Case Study 1: Improving the birthing experience

The benefits/risks associated with water birth have been discussed by the medical profession and by patients (mothers) and it is suggested that the 'enveloping effect of the water wrapped the women in warmth and provided a sense of privacy, whilst enabling them to deal with their pain without the need for pharmacological pain relief'. However the design of birthing pools (large barrels) created a barrier for use with mothers finding it very difficult to get into the birthing pool and almost impossible to get out in an emergency. As part of an HFE project, a detailed analysis was carried out to map the stakeholders:

- Mothers (and their partners): enter/exit the pool; support in a range of positions during labor.
- Clinical staff: care for the mother including examinations and monitoring.
- Baby: may need emergency assistance.
- Maintenance, cleaning and infection control support staff.

An iterative prototyping approach was taken, including a scale mock-up which was evaluated in the hospital. A new birthing pool was designed to support independent access/egress with steps and hand rails; a range of labor and birthing positions; staff examinations using a concave side; and delivery and perineal examination plus emergency exit of the mother via a horse-shoe shaped seat. This
HFE design project revolutionized the design of birthing pools resulting in its international adoption\(^3\).  

3.1.2 Case Study 2: Design for Neonatal Intensive Care Unit (NICU)  

In the United Kingdom (UK), the NICU is often one large, open room with the cots (incubators) side by side. This has observation and access advantages but disadvantages relating to noise, lighting, and privacy\(^32\)\(^33\). Recently there has been increased provision of single rooms aiming to improve privacy and reduce movement (and infection transmission risks) around the unit and between departments.\(^34\)\(^35\). The Department of Health \(^36\) responded to these changes in clinical care by conducting a review of UK design guidelines for neonatal units to determine the space required to care for and treat neonates. They engaged an HFE team to look at the spatial requirements using a 5-step process\(^37\) to support decision making for clinical space planning in healthcare facilities by:  

1. Defining the clinical specialty and space  
2. Collecting data (using task analysis methods) with clinical staff and neonates to produce a simulation scenario representing the frequent and safety-critical activities.  
3. Calculating the average spatial requirements through functional space experiments.
4. Incorporating additional data for storage and circulation to produce a spatial recommendation.

5. Reviewing and verifying the recommendations to consider alternative layouts and technology.

HTA and LA were used to understand and evaluate space use and then develop a test scenario on the basis of the frequency and criticality of activities. Clinical tasks were observed with 28 staff providing care to 15 newborn babies and staff actions/task behaviors were recorded for 21 clinicians using multi-directional video data to plot the movements of each participant, equipment, and furniture during the tasks.

It was found that there was no family space for the parents to stay with their child; storage was limited; there were no nursing trolleys and clinical bins in the cot space; and staff sometimes worked in awkward positions due to the cramped space. Recommendations were made for the dimensions of individual clinical neonatal cot space (13.50 m² [or 145.3 ft²], width 4.13 m [or 13.6 ft] × length 3.27 m [or 10.7 ft]); these were reviewed and validated by the expert group. The complexity of the spatial requirements suggests that circulation and storage considerations must be included for both single and multiple NICU cot spaces.
3.2 Child to Adult

3.2.1 Case Study 3: School design

The design of the educational environment has many HFE challenges in relation to furniture, classroom layout, equipment, individual storage, lighting and ventilation. A useful overview of design issues for school stakeholders is offered by Nair and Fielding\textsuperscript{41} in the context of both construction and renovation of schools, and evaluation of the educational adequacy of existing school facilities.

Both neck and back pain have been researched with significant association reported for school furniture features, school back weight as well as family history and personal problems (emotional and conduct)\textsuperscript{42}. Milanese and Grimmer\textsuperscript{43} investigated the relationship between reported spinal symptoms in an adolescent student population and the match between their individual anthropometric dimensions and their school furniture. Data were collected from 1269 pupils to investigate back pain symptoms and anthropometric challenges. Overall, a higher probability of reporting low back pain was reported for students with anthropometric dimensions in the fourth quartile (the tallest students). Detailed anthropometric measurements were collected to investigate furniture incompatibility for 180 children (7-12 years) in Greece for stature, elbow height, shoulder height, upper arm length, knee height, popliteal height and buttock–popliteal length. It was found that chairs were too high and too deep and desks
were too high\textsuperscript{44}. There are now design standards for school furniture to prevent the exposure to these musculoskeletal risks\textsuperscript{45}.

3.2.2 Case Study 4: Design for Adolescents

Adolescence covers the life period of 10 to 19 years\textsuperscript{46} when individuals grow from dependent children into independent adults. Lang et al\textsuperscript{47} explored the different design requirements that might improve compliance with medical device use during this changing period. They found that usability could be improved by allowing a level of customisation (both for operation and appearance).

One difference in the use of the build environment has been identified for younger wheelchair users when designing their work space where it cannot be assumed that an individual will transfer from their wheelchair to local seating. Nowak reported that adolescents preferred to stay in their wheelchair to avoid both additional effort and asking for assistance\textsuperscript{48}. For interior architecture this has two ramifications in providing interfaces (built and furniture) suitable for wheelchairs but also providing space to include the wheelchair as an additional piece of furniture (with storage/space for rejected seating!).

There is limited research on this age group, but the included studies point to the development of individual preferences as more choice becomes available with increasing independence.
3.3 Growing Older

3.3.1 Case Study 5: Workstation design

This case study focuses on the personal workspace associated with computer use, a pertinent concern given their widespread use for work or leisure. A workstation assessment considers the extent to which the task and environment contribute to the users’ health and well-being with the aim of promoting safe, comfortable and efficient engagement with associated activities. By assessing people’s abilities and limitations, their jobs, equipment and working environment and the interaction between them, it is possible to design safe, effective and productive work systems\(^4^9\). Ergonomics advice is available, often in the form of generic guidelines such the Computer workstations e-Tool\(^5^0\) and Display Screen Equipment (DSE) workstation checklist\(^5^1\) and personalized health solutions can be developed as the following case study illustrates.

An office worker experienced: cold extremities due to Raynaud’s Syndrome; musculoskeletal pains and visual discomfort. The design of the workstation and work flow was investigated through measurement of the workplace, observation of working practices and application of relevant regulations. Physical and procedural adjustments were recommended including a heated footrest to reduce the Raynaud’s Syndrome symptoms, document holder and re-location of the hard drive (to reduce the musculoskeletal strain), second screen to reduce visual discomfort; and advice on the need for breaks and postural...
change. This HFE approach resulted in low-cost solutions which reduced discomfort, improved morale and reduced the risk of absenteeism\textsuperscript{52}.

3.3.2 Case Study 6: Empathic modelling

As the global population ages, designers can often be younger than those for whom they are designing. It has been suggested that there is a need to increase awareness and understanding of users with different capabilities, limitations and needs – also known as stretching the Empathic Horizon\textsuperscript{53}. Human-Centred Design (HCD) as a component of a wider HFE approach, for example investigating ‘why, how and what’\textsuperscript{54} as part of a wider HFE approach which will also include ‘who, where and when’\textsuperscript{55}. The HCD cycle is an established model to incorporate user needs and desires based on the international standard ISO 9241-210\textsuperscript{56}.

This can be facilitated through the use of empathic-modelling tools, such as LUSKInS (Loughborough University Sensory and Kinesthetic Interactive Simulations). This range of wearable simulations supports designers in their understanding of the health conditions of others by enabling direct experience of some of the associated symptoms and their consequent impacts to daily living\textsuperscript{57}.

Drawing on primary and secondary data, the first LUSKInS (Third Age Suit), a whole-body wearable simulation, was developed for the Ford Motor Company to simulate aspects of reduced joint mobility, tactile sensitivity and vision\textsuperscript{58}. The simulation was then transferred to the aerospace industry via a
technology-sharing alliance, leading to an improvement in the design of the aircraft environment in terms of visibility and physical access. It has subsequently been used by architects as part of a hospital design programme, where the architects ‘found the simplest of tasks, such as sitting down, standing up and reaching out the arm became laboured and difficult when wearing the suit’\textsuperscript{59}. The psychological impact of reduced confidence due to the increased challenges when interacting with the environment were reported\textsuperscript{60}, which emphasizes the importance of considering all aspects of human-environment interactions.

3.3.3 Case Study 7: Kitchen design

The Instrumental Activities of Daily Living (IADLs) define daily activities supporting independent living within the community and include meal preparation, which has implications for the role of kitchen design\textsuperscript{61}. A research programme project ‘Transitions in Kitchen Living’ investigated the problems and needs of older people when using their kitchens independently\textsuperscript{62}. Interviews with 48 older people who lived in a variety of homes including detached houses, apartments and sheltered accommodation, identified a number of issues including:

- Wall cupboard shelves too high.
- Poor lighting, especially in the cooking area.
- Window handles difficult to reach.
- Sinks and worktops at an inconvenient height.
• No space for a table for seated activity.

Coping strategies had been developed including stools or steps, installing table lamps or stick-on LED lights. Other adaptations had been made at the installation stage, for example by fitting cupboards at more convenient heights.

Through a HFE approach, kitchen designs which adapt to users’ needs (as they age) could include pull-down wall cupboards, adjustable height work surfaces and the installation of mid-level ovens to eliminate the need for reaching and bending. The challenge is to make kitchen flexibility a market standard so that everyone can use their kitchen optimally.

3.3.4 Case Study 8: Design of dementia care environments

Dementia is predicted to become increasingly prevalent in the future, creating a challenge in providing appropriate housing where the design of the environment can contribute towards the management of illness. As the demography of higher income countries changes and the baby boomer generation ages there are more older (and oldest old) being cared for in specialist facilities. Care environments specifically designed for dementia can help maintain or foster a sense of independence, and encourage participation in activities which could potentially maintain a higher quality of life for longer.

To explore this area further, a review of the guidelines for dementia design was undertaken which found inconsistencies in the advice. A systematic
literature review was then undertaken to investigate the robustness of the
guidance in terms of degree of variance and whether HFE principles had been
considered. An initial scoping study mapped key HFE issues relating to the design
of dementia care environments to illustrate different dementia diagnoses,
physical, emotional and psychological needs, design challenges and research
(investigation) methods (Figure 2).

The complexity of the design challenge can be illustrated when a combination of
negative environmental conditions such as lack of lighting, poor air quality
(including odors from cleaning products\textsuperscript{68}), excessive temperatures and high noise
levels contributed to wandering and agitated behaviors\textsuperscript{69, 70, 71, 72}. Conversely,
higher levels of lighting, lower levels of noise, good air quality and an ambient
temperature were linked to improved nutritional intake\textsuperscript{73} and being able to smell
cooking was thought to boost nutritional intake as an appetite stimulant\textsuperscript{74}.

4.0 Conclusion

Within this chapter the role of HFE expertise and methods have been outlined in
the design of environments through the lifespan. An HFE approach can support
the design of more accommodating (better fit and more useable) environments by
ensuring that user needs are identified and met. In addition to improving performance (human-environment interactions) there may be cost-saving benefits through reduced accidents, improved well-being and living independently for longer. Including HFE knowledge and principle early in the design process will be less expensive with maximum benefits from including HFE expertise as part of the design team. The case studies demonstrate that HFE can make valuable contributions to health and wellbeing across the life course through the application of a range research and evaluation methods.
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