

AN ACTION RESEARCH APPROACH TO SHARING SPECIALIST CONSTRUCTION KNOWLEDGE

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In recent years, a key growth area for Ireland's leading building contractor Sisk has been the biotechnology, pharmaceutical and medical devices sector. Much of the company's work in this area involves the construction of highly complex cleanroom facilities which are typically delivered through the management contracting route. This allows Sisk's knowledge and experience to be utilised in the early stages of design development, leading to time and cost savings for clients. Recognising the need to manage knowledge in a more formal manner within Sisk's Pharma division, an action research approach was adopted. Based on a collaborative approach between the researcher and the practitioner, action research is geared towards solving real problems and generating new knowledge. It involves a cyclical process whereby the application of findings and an evaluation of their impact on practice become part of a cycle of research. The first phase of the research involved developing a formal approach for sharing knowledge across projects within the Pharma division. This was achieved through a three-stage approach. Firstly each member of the Pharma division's management team was individually interviewed to identify key issues related to cleanroom construction, management contracting and knowledge management. Once the results were collated and analysed, a focus group session was conducted with a view to collectively sharing knowledge of cleanrooms between the interview participants. Finally, the focus group was evaluated through a questionnaire, seeking to assess the feasibility for future knowledge-sharing activities. It was concluded that such an approach to knowledge sharing has potential for greater use within the Pharma division and the wider Sisk organisation. A number of recommendations are made relating to the improved delivery of cleanroom projects and the next phase of the action research identified.

Keywords: action research, cleanrooms, focus group, knowledge management, management contracting.

INTRODUCTION

Cleanrooms form an essential part of the production process across a range of industries, such as electronics, micromechanics, optics, bio-technology, pharmaceutical, medical devices and food production. John Sisk & Son, the leading contracting firm in Ireland, have gained considerable experience in the delivery of complex projects for clients in the biotechnology, pharmaceutical and medical devices sectors. Sisk have been retained by a number of these clients for repeat projects in a management contracting role, and have subsequently established a dedicated Pharma division. The design, construction, commissioning, and validation of cleanroom facilities within these projects are significant challenges for all involved. Constantly

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caught in a dilemma of budget and schedule constraints, companies have to deliver a quality building that complies with relevant codes and regulations (Wrigley, 2004). Construction organisations such as Sisk rely on the knowledge, experience and skills of their employees, to execute increasingly complex construction projects as efficiently as possible. Fong and Wong (2005: 70) identify the transfer of knowledge across projects as a major challenge for construction organisations, stating that “it is common for specialist and technical knowledge to become lost from one project to the next.” Despite these challenges, Sisk do not have any formal approach to managing their specialist knowledge of cleanrooms. However if they were to adopt a more formal approach, it could potentially improve their effectiveness as management contractors. The purpose of this paper is to present the first phase of an action research project which is seeking to improve the sharing of specialist construction knowledge within the company's Pharma division. A review of relevant literature is presented, followed by the action research methodology adopted with findings presented and discussed. A number of conclusions are drawn and recommendations made for improving the sharing of specialist construction knowledge.

LITERATURE REVIEW

In order to appreciate the complexities of cleanrooms, Management Contracting and knowledge management (KM), the following literature review considers each topic individually.

Cleanrooms

A cleanroom is defined by Whyte (2005: 6) as “a room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimise the introduction, generation and retention of particles inside the room and in which other relevant parameters e.g. temperature, humidity and pressure, are controlled as necessary.” In designing a cleanroom it is necessary to consider the anticipated use of the room, equipment arrangement, flow diagrams, HVAC zoning and room classifications, budget, quality, scope of work, a realistic project schedule, and relevant regulatory authorities for which the facility will have to be validated (Smith, 2005). The internal floor, walls and ceilings must be finished to an exceptionally high standard, with a number of different systems on offer, careful consideration should be given to the selection of these (Whyte, 2005; Pearson, 2005). Control of air movement is extremely important and considerations include filtration standards, allowable contamination levels, pressure relationships between adjacent spaces, air flow patterns and distribution (Anghel and Chetwynd, 2002). While the introduction of building management systems (BMS) has improved the monitoring and control of a cleanroom environment, such systems have contributed further to the complexity of cleanrooms, from design, through to operation and maintenance (Wood, 1999). The cleanroom must be subjected to rigorous commissioning and validation procedures, which typically involve design review, installation verification, proper system start-ups, functional performance tests, operations and maintenance training, and complete documentation of the HVAC system. For the best possible results, commissioning should be included in all phases of the design and construction process and involve all relevant consultants and contractors (ACG, 2007). The process of validation requires that it complies with specific regulations for current good manufacturing practice (cGMP) and depends on the jurisdiction of the facility and the relevant regulatory body, of which there is a diverse range (Bonanomi, 2006).

Management Contracting

The predominant procurement route chosen by Sisk's pharmaceutical clients is Management Contracting, whereby the contractor is engaged by the client to manage the whole of the building process and is paid a fee for doing so. It is considered to be a 'fast track' strategy, which is achieved by overlapping the design and construction thus achieving a reduction in project time (Morledge *et al.*, 2006). This route allows for early contractor involvement in the design development process, the contractor being incorporated into the design team or an equivalent basis to all the other consultants (Walker and Hampson, 2002). Due to this overlapping of design and construction, together with the management contractors experience with buildability and technical issues, considerable time can be saved that other procurement methods cannot achieve (Morledge *et al.*, 2006). Competition between management contractors occurs at appointment stage, where presentations are given by management contractors on their proposals to the client and the design team. These proposals are typically assessed on programme, financial soundness, technical ability/buildability considerations, safety performance, reputation, the procurement of work packages, and the control of information flow (Cooke and Williams, 2004).

Knowledge Management

One of the central debates surrounding KM is the approach adopted to managing tacit and explicit knowledge. Payne (2003) identified tacit knowledge as being not easily visible or expressible, highly individualised and context specific, difficult to share and manage. Explicit on the other hand can be readily codified into words and numbers, easily shared, easy to distribute, and can be managed as information. Early research into KM focused on the use of technology to manage explicit knowledge, however it is now more widely recognised that the management of tacit knowledge and socialisation is more valuable (Egbu, 2004). Every day on construction projects, new problems are encountered and solutions arrived at which are rarely documented, the lessons learned residing only with those individuals directly involved in the problem-solving process (Kazi *et al.*, 2005). That much knowledge is experiential and inherently tacit, Quintas (2005) highlights the limitation in attempting to codify or capture such knowledge into an explicit form. In considering managing construction project knowledge, Kamara *et al.* (2005) highlights the importance of transferring knowledge from projects to the organisational knowledge base (OKB). A number of organisational knowledge sharing activities are identified by Dainty *et al.* (2005) as informal knowledge workshops, knowledge exchange seminars, departmental meetings, site visits, reports, intranet and mentoring, most of which focus upon social interaction. For such activities to be successful, Kamara *et al.* (2005) states that the individuals involved should have a high level of involvement throughout the project, must be given time to reflect and consolidate their learning and should be committed to staying with the organisation. In addition, there are a number of challenges in attempting to transfer specialist knowledge from projects to the OKB:

- The reluctance of practitioners to share their experiences and knowledge with others (Fong and Wong, 2005)
- Knowledge acquired through experience is "impossible to communicate or share with others who have never been through similar learning experiences (Quintas, 2005: 21)."
- The identification and maintenance of 'high-grade' knowledge which can be reused in other projects (Kamara *et al.*, 2005)

Robinson *et al.* (2005) place particular emphasis on the importance of knowledge stocks and flows. They consider knowledge stocks to be the talents of employees, efficiency of organisational procedures and the nature of relationships with other stakeholders, knowledge flows being the activities (e.g. seminars, mentoring and intranet) used to improve the stocks.

RESEARCH METHODOLOGY

The need to identify and share specialist cleanroom knowledge is particularly relevant to Sisk's Pharma division in the management contracting route, where the exploitation of experience is crucial to winning and completing projects. In order to address the current challenges faced by Sisk in the procurement and construction of cleanrooms through management contracting, action research was adopted as the overall research strategy. This approach has been chosen as it is based on a collaborative approach between the researcher and the practitioner with the aim of solving a problem and generating new knowledge. According to Denscombe (2003) it is normally associated with 'hands-on', small-scale research projects where practitioners wish to use research to improve their practices. The participants in the action research comprise the six members of the Sisk Pharma management team (see Table 1), all of whom have considerable experience in cleanroom projects. The researcher is currently involved in conducting a wider study into KM in the leading Irish construction organisations, while the collaborating practitioner, Contracts Manager C, conducted this research for his dissertation as part of an MSc in Construction Project Management on KM in Sisk's Pharma division. Denscombe (2003) views the practitioner as the dominant partner with the academic acting as a facilitator in the research. This was the approach adopted in the present study. A three-stage approach to primary research was devised, comprising interviews, a focus group and a questionnaire.

Table 1: Research Participants

Position	Industry Experience (Years)	Sisk Experience (Years)	Current Project Value (€ million)
Pharma Director	30	30	180
Senior Contracts Manager A	19	14	180
Senior Contracts Manager B	12	12	110
Contracts Manager A	18	10	55
Contracts Manager B	15	13	180
Contracts Manager C	16	15	100

Interviews

As an active participant in the research process, Contracts Manager C conducted semi-structured interviews with his five colleagues. Blomberg *et al.* (2003) state that interviews are an appropriate method of research where there is a need to collect in-depth information on people's opinions and experiences, particularly relating to complex topics. In this regard, the interviews sought to identify each individual's knowledge stock based on their experiences of cleanroom projects and management contracting and their views on how knowledge is presently managed within the organisation. Interviews are not without their limitations, particularly as there is room for considerable bias in what questions are asked and how they are interpreted (Blomberg *et al.*, 2003).

Focus Group

The interviews were transcribed and analysed in order to identify high-grade knowledge in the procurement and construction of cleanrooms which formed the basis for a knowledge sharing seminar, structured as a focus group. According to Litosseliti (2003: 1), focus groups “are small structured groups with selected participants, normally led by a moderator. They are set up in order to explore specific topics, and individuals’ views and experiences, through group interaction.” All research participants attended the focus group, with the exception of the director, who was unavailable due to prior commitments. The role of the moderator is very important to the success of a focus group, which Fern (2001) identifies as a facilitator or discussion leader, not a discussion participant. The academic collaborator acted as moderator for the session, allowing Contracts Manager C to engage fully in the focus group discussion with his colleagues. Much time and effort went into planning the focus group and an agenda was devised to ensure that the discussion was kept on track (Litosseliti, 2003). The session, which lasted for approximately three hours was conducted in the academic collaborator’s institute and was video recorded to allow for later analysis.

Questionnaire

A brief one page questionnaire was then administered to all of the focus group participants in order to clarify a number of issues arising from the focus group and to help with making recommendations for future KM activities within the Pharma division. There are many well-recognised limitations of questionnaires; poor responses rates, a lack of opportunity to clarify issues and the ability of the respondent to readily answer the questions (Oppenheim, 2001). In order to minimise these issues, Contracts Manager C administered the questionnaire and elicited responses over the telephone.

It can be seen that there are significant challenges in the application of the individual data collection methods; for example bias in interviews, engagement of all participants in a focus group and misinterpretation of questionnaires. However through the adoption of three data collection methods, many of these issues can be addressed, with methodological triangulation being achieved, the purpose of which is to confirm findings through convergence of different perspectives, check the integrity of inferences drawn and ensure validity (Jack and Raturi, 2006).

FINDINGS

Interviews

The respondents discussed a range of issues relating to cleanrooms including, finishes, services, the appointment of specialist contractors and commissioning and validation. A wide variety of problems have been encountered by the respondents in managing the construction of cleanrooms in areas such as floor, wall and ceiling finishes, the application of silicone, the integration of services into a cleanroom environment, services design and installation, ducting layouts, and setting and maintaining pressures. There was much time spent discussing the most appropriate type of wall and ceiling construction to use in a cleanroom, and all respondents agreed that a modular factory wall panel system and a grid ceiling system were preferable due to the quality of finish, speed of erection and improved services integration. The Pharma Director spoke about his current project where “the client was insisting on using stick built with plasterboard because an equivalent plant in Europe was built that way.

Weeks were spent proving that the modular wall system was cheaper and better, particularly because the quality of plasterboard contractors in this country leaves a lot to be desired.” The timing of the appointment of the cleanroom contractor was viewed by all as a very important issue, with all agreeing that this should happen as early as possible in the project. Senior Contracts Manager B stated that “the cleanroom contractor needs to be involved in the early stages of design before the mechanical and electrical contractors are appointed.” Based on their experience, a number of the respondents felt that the cleanroom contractor should supply and install all fixtures and fittings within the cleanroom. This did not happen on Contracts Manager C’s project and thus required his project team to undertake considerable coordination of all subcontractors and suppliers within the cleanroom. The commissioning and validation process was also viewed as being highly problematic, with a lack of time within the construction programme for this intensive process being a major issue. Early commencement of commissioning and validation, the issuing of documentation and the role of the client in the process were also viewed as areas where improvement was required.

All respondents indicated that their projects were procured under management contracting, with the exception of Senior Contracts Manager B, who stated that the client was indecisive when it came to the selection of a procurement route. He noted “because of the delay in selecting the procurement path, there was 6 months lost on pre-construction and coordination which was a big mistake.” As a management contractor, it was found that the level of experience of the client with this procurement route and indeed, in building has an impact on the outcome of the project from Sisk’s perspective. In most cases Sisk have been appointed approximately 6 months before starting on-site, allowing for their experience and knowledge of buildability issues to be used in the design process. There was general agreement that management contracting is the best procurement route for such large scale, fast track projects, however the main complaint from all respondents was that the design process took longer than allowed, thus impacting on the construction schedule.

It was acknowledged by all that knowledge sharing within the Pharma division was relatively informal and that through a more formal approach, the delivery of cleanroom projects could be improved. Site visits, a bi-annual knowledge sharing forum and the use of the company’s intranet for documenting experience were suggested as tools for sharing knowledge. There have been attempts by a number of the interviewees to conduct project reviews and document the lessons learned, but with little success, according to Senior Contracts Manager A, “there were great plans to do it, but it never really transpired.” The willingness of people within Sisk to share their experiences with others was also discussed, and all respondents felt that there was an open culture within the organisation. Overall, there was a consensus that a more formal approach to KM was needed within the Pharma division in order to develop and maintain a competitive advantage over rival contractors. The Director felt that “by standardising the way we do things, we can reduce mistakes and demonstrate our expertise to clients and design teams.”

Focus Group

Based on the interviews findings, an agenda was developed for the focus group with particular emphasis on the appointment of the cleanroom contractor, recurring cleanroom design and quality issues, commissioning and validation, Sisk’s role as a management contractor, and the development of KM within the Pharma division.

Through facilitated discussion, the high-grade knowledge identified in the interviews was further refined and consolidated during the course of the focus group. The following points reflect the consensus of the Pharma division's management team who participated in the focus group:

- Cleanroom contractor appointment: The cleanroom contractor employed by Sisk should be appointed as early as possible, although the timing may vary dependent upon project-specific issues. It was proposed that the need to do this should be documented and presented to the client, based on previous project experiences.
- Design and quality issues: It was originally intended to discuss a range of issues relating to finishes and services, however, after a lengthy and comprehensive discussion on floor finishes, it was realised that a three hour focus group would not suffice. In order to reduce problems with these issues, it was agreed that quality alerts be compiled and emailed to all Pharma staff on a regular basis; lessons learned documented and posted on Sisk's newly established intranet and site visits arranged at various stages of projects to share experiences.
- Commissioning and validation: It was agreed that there is a lack of expertise within Sisk in the commissioning and validation domain, and that the recruitment of specialists and training of existing staff is required. In addressing problems of setting pressures, relative humidity and temperatures during commissioning, it was suggested that a window should be left in the programme to get systems up and running. Commissioning and validation meetings should be started during pre-construction, with the focus group agreeing the following agenda: scope, strategy, schedule and critical path, sequence of critical items and systems, design documents, procedures and personnel involved, approval sequences, documentation contents and test pack formats and system boundaries.
- Management Contracting: In order to be more proactive with the client and design team with regards to changes, it was proposed that Sisk have an individual working in the design office. Through this approach, buildability issues could be considered earlier, problems pre-empted and information requirements defined.
- Knowledge management: The group agreed for the need to develop formal procedures for KM within the Pharma division and indeed the wider organisation. Based on initial feedback at the focus group, all agreed that such a structure for knowledge sharing was particularly useful and would encourage attendance at future KM activities.

Questionnaire

The main purpose of the questionnaire was to evaluate the focus group as a framework for knowledge sharing within the Pharma division. All participants agreed that the focus group was of benefit to them and that they had learned a lot from such an approach to sharing knowledge. They were unanimous in their view that such an activity should become a regular occurrence within the Pharma division. In order for this to happen it was suggested that a strategy for KM should be developed and agreed, and an agenda developed for the focus groups on relevant/specific topics. Contracts Manager A suggested that depending on the topics, other key people within the division should attend, including building services engineers, foremen etc. Again, all felt that knowledge sharing methods such as the focus group, lessons learned,

email alerts and site visits could improve the delivery of Pharma projects, with Senior Contracts Manager A stating that any major conclusions derived from such activities should be “taken forward as policy.” In order to improve the knowledge stocks of the Pharma division, training in the area of cleanrooms and particularly commissioning and validation should be provided. Senior Contracts Manager B also suggested that the division should explore the possibility of hiring people who specialise in commissioning and validation.

DISCUSSION

It has been shown that the procurement and construction of cleanroom projects pose significant challenges for Sisk's construction management staff. The inherent complexities of such projects and the use of management contracting emphasise the need for improved sharing of specialist construction knowledge between the Pharma divisions management team. To this effect, an action research approach was adopted comprising interviews, a focus group and a questionnaire. The use of action research in conjunction with methodological triangulation helped to minimise the challenges faced in attempting to transfer specialist knowledge from projects to the OKB. For example, by interviewing each practitioner individually, there was an opportunity to share knowledge in a safe, one-to-one environment, prior to moving onto the focus group, thus eliminating the reluctance to do so (Fong and Wong, 2005). This also allowed for the identification of high-grade knowledge based on interview findings, which then become central to the discussions of the focus group (Kamara *et al.*, 2005). The focus group provided a platform for people of similar learning experiences to communicate and share their highly context-specific knowledge (Quintas, 2005). Indeed, it is evidenced in Table 1, that not only do all of the participants have considerable experience in the construction industry they have also spent a significant proportion of their working lives with Sisk. Coupled with their high level of involvement in their respective cleanroom projects, this demonstrates their commitment to the company and supports the respondents views of an open culture within Sisk, which Kamara *et al.* (2005) identify as requirements for successful knowledge sharing. The careful selection of the research participants, based on their experience, level of involvement in cleanroom projects and commitment to Sisk allowed for the effective sharing of highly context-specific specialist construction knowledge. While all participants viewed the focus group as a good forum for knowledge sharing, measuring its success is problematic. The agenda which was developed from the interview findings and the subsequent focus group discussion highlighted the wealth of knowledge and experience within the Pharma division's management team. The limitations in attempting to capture or codify, experiential, tacit knowledge highlighted by Quintas (2005), also applies to the measurement of such endeavours. There is no doubt that the action research process (knowledge flow) undertaken is an effective approach to sharing specialist construction knowledge and has contributed to enhancing the division's knowledge stocks. The extent of its effectiveness, is not easily articulated, however if the recommendations from the focus group and questionnaire were implemented, the talents of employees and efficiency of organisational procedures could be greatly improved.

CONCLUSIONS

This paper has established that the procurement and construction of cleanrooms through management contracting is a highly knowledge-intensive activity on the part of the management contractor. The requirement for an exceptionally high level of

finishes, coupled with the complexity of services integration and rigorous commissioning and validation procedures place considerable demands upon the management contractor. John Sisk & Son, who are leader in delivering such projects in Ireland, have established a Pharma division to strategically grow this important area of business. The research has shown that the company does not have any formal approaches to managing knowledge, particularly in transferring knowledge from individual projects to the organisational knowledge base. Through an action research approach, a focus group was used as a forum for sharing specialist cleanroom knowledge between members of Sisk's Pharma division. Based on the action research, the following recommendations can be made for improving the sharing of specialist construction knowledge in construction organisations:

1. A moderated focus group with a structured agenda is a useful tool for sharing highly- contextual knowledge between staff who are experienced, have a high level of involvement in projects and are committed to the organisation.
2. Recommendations arising out of the focus group should, where appropriate, become part of the organisation's procedures and standard practices.
3. The knowledge sharing focus group should be supplemented by other activities such as site visits, email alerts and documentation of lessons learned at the end of each project.
4. Based on the identified need for lessons learned, the next phase of the action research will seek to review and document the main lessons arising from Contracts Manager C's current €100 million cleanroom project.

REFERENCES

- ACG (2007) AABC Commissioning Group Website [Internet], Washington DC, USA. Available from: <<http://www.commissioning.org>> [Accessed 21st April, 2007]
- Anghel, V. and Chetwynd, D.G. (2002) Creating a low-cost, ultra clean environment. *Precision Engineering*, **26**(1), 122-127.
- Blomberg, J., Giacomi, J., Mosher, A., & Swenton-Wall, P. (1993) Ethnographic Field Methods and Their Relation to Design. In: D. Dchuler and A. Namioka (Eds.) *Participatory Design: Principles and Practices*. New Jersey: Erlbaum.
- Bonanomi, D. (2006) The State of Validation in the European Union. *Pharmaceutical Technology Europe*, **17**(12), 17-20.
- Cooke, B. and Williams, P. (2004) *Construction Planning, Programming and Control*. Second Edition. Oxford: Blackwell Publishing.
- Dainty, A. R., Qin, J. and Carrillo, P. (2005) HRM Strategies for Promoting Knowledge Sharing within Construction Project Organisations: A Case Study. In: Kazi, A. S. (ed.), *Knowledge Management in the Construction Industry: A Socio-Technical Perspective*. London: Idea Group Publishing.
- Denscombe, M. (2003) *The Good Research Guide: For Small-Scale Research Projects* Second Edition. Buckingham: Open University Press
- Egbu, C. (2004) Managing knowledge and intellectual capital for improved organisational innovations in the construction industry: an examination of critical success factors. *Engineering, Construction and Architectural Management*, **11**(5), 301-315.
- Fern, F.E. (2001) *Advanced Focus Group Research*. London Sage Publications

- Fong, S. W. and Wong, K. (2005) Capturing and Reusing Building Maintenance Knowledge: A Socio-Technical Perspective. In: Kazi, A. S. (ed.), *Knowledge Management in the Construction Industry: A Socio-Technical Perspective*. London: Idea Group Publishing.
- Jack, E. P. and Raturi, A. S. (2006) Lessons learned from methodological triangulation in management research. *Management Research News*, **29** (6), 345-357
- Kamara, J. M., Anumba, C. J. and Carrillo, P. M. (2005) Cross-Project Knowledge Management. In: Anumba, C., Egbu, C. and Carrillo, P. (eds.), *Knowledge Management in Construction*. Oxford: Blackwell Publishing.
- Kazi, A. S., Koivunieme, A. and Moksen, P. (2005) Use of Social Processes for Good Practice Capture in Project Based Businesses: The Case of YIT Construction. *Proceedings of CIB W102 Meeting and International Conference*, Instituto Superior Tecnico, Lisbon, May 19-20, 2005, pp. 45-54, CIB
- Litosseliti, L. (2003). *Using Focus Groups in Research*. London: Continuum.
- Morledge, R., Smith, A. and Kashiwagi, D. (2006) *Building Procurement*. Oxford: Blackwell Publishing.
- Oppenheim, N.A. (2001) *Questionnaire Design, Interviewing and Attitude Measurement*. London: Continuum
- Payne, J. (2003) Knowledge Management in Construction Toolkit (CD-ROM). Knowledge Management in Construction Project Partners
- Pearson, M. (2005) Designing and implementing pharmaceutical cleanrooms. *Pharmaceutical Technology Europe*, **17**(6), 34-38.
- Quintas, P. (2005) The Nature and Dimensions of Knowledge Management. In: Anumba, C., Egbu, C. and Carrillo, P. (eds.), *Knowledge Management in Construction*. Oxford: Blackwell Publishing.
- Robinson, H. S., Carrillo, P. M., Anumba, C. J. and Al-Ghassani, A. M. (2005) Performance Management in Knowledge Management. In: Anumba, C., Egbu, C. and Carrillo, P. (eds.), *Knowledge Management in Construction*. Oxford: Blackwell Publishing.
- Smith, S. (2005) Building the future into biopharmaceutical design. *Cleanrooms*, **19**(11), November 2005, PennWell.
- Walker, D. and Hampson, K. (2002) *Procurement Strategies: A Relationship-Base Approach*. Oxford: Blackwell Publishing.
- Whyte, W. (2005) *Cleanroom Design*, Second Edition. Chichester: Wiley Publications
- Wood, B. (1999) Intelligent Building Care. *Facilities*, **7**(5/6), 189-194.
- Wrigley, G. (2004) *Facilities Validation: Theory, Practice and Tools*. Texas: Culinary and Hospitality Industry Publication Services.