CCC 2018

Proceedings of the Creative Construction Conference (2018)
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
DOI 10.3311/CCC2018-111

Creative Construction Conference 2018, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia

Designing for Construction Ergonomics in Slovenia

Alenka Temeljotov-Salaj [a], John Smallwood [b]

[a]*Norwegian University of Applied Science and Technology, NO-7491 Trondheim, Norway*
[b]*Department of Construction Management, Nelson Mandela University, PO Box 77000, Port Elizabeth, 6031, South Africa*

Abstract

Relative to other industries worldwide, the construction process generates a disproportionate number of fatalities, injuries, and disease, and both the direct and indirect costs contribute to the cumulative cost of construction.

Designers influence construction ergonomics directly and indirectly. The direct influence is because of design, details and method of fixing, and depending upon the type of procurement system, supervisory and administrative interventions. The indirect influence is because of the type of procurement system used, pre-qualification, project duration, partnering, and the facilitating of pre-planning.

The purpose of the paper is to present the results of a study conducted among designers in Slovenia using a self-administered questionnaire, to determine their perceptions and practices relative to construction ergonomics. Descriptive statistics in the form of frequencies and a measure of central tendency were computed from the collected data.

The following constitute the salient findings. Cost, quality, and time are more important to designers than construction ergonomics and project health and safety (H&S). Ergonomics during the construction, and design phases are more important to designers than the other phases. A range of design related aspects impact on construction ergonomics. To a degree, construction ergonomics is considered on most design, procurement, and construction occasions by designers. Practice notes predominate in terms of how designers' ergonomics knowledge was acquired. A range of aspects have the potential to contribute to an improvement in knowledge, and the application of construction ergonomics.

The paper concludes that designers contribute to construction ergonomics, but that there is potential for and a clear need for enhanced contributions. Recommendations include the inclusion of construction ergonomics in designers' tertiary education, and continuing professional development (CPD), to remedy shortcomings in practitioners' knowledge.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2018.

Keywords: Construction; Designers; Ergonomics

1. Introduction

The Council Directive 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile constructions sites [1] states that unsatisfactory architectural and/or organizational options or poor planning of the works at the project preparation stage have played a role in more than half of the occupational accidents occurring on construction sites in the Community. This amplifies the need for 'designing for safety', which Behm [2] defines as "The consideration of construction site safety in the preparation of plans and specifications for construction projects."

Design is an important stage of projects, as it at this stage that conceptual ideas are ideally converted into constructable realities [3]. 'Designing for H&S' being one of the designing for constructability principles. Thorpe [3] further states that designing for safety is one of a range of considerations that need to be balanced simultaneously

John Smallwood: john.smallwood@mandela.ac.za

during design, and highlights that it is an integral part of the overall design process as doing so will result in safer construction and maintenance of structures and facilities.

Slovenian legislation and international literature highlight the relevance of designing for construction ergonomics, which resulted in a study that was conducted among designers, the objectives being to determine relative to respondents and their practices, the:

- Importance of project parameters;
- Importance of ergonomics during the various project phases;
- Frequency at which they consider construction ergonomics on various occasions and relative to various design related aspects;
- Extent to which various design related aspects impact on construction ergonomics;
- Source of ergonomics knowledge, and
- Potential of various aspects to contribute to an improvement in construction ergonomics.

2. Review of the literature

2.1. Recommendations pertaining to designers

The International Labour Office (ILO) [4] as early as 1992 recommended that designers should: receive training in H&S; integrate the H&S of construction workers into the design and planning process; not include anything in a design which would necessitate the use of dangerous structural or other procedures or hazardous materials which could be avoided by design modifications or by substitute materials, and consider the H&S of workers during subsequent maintenance.

2.3 Designing for construction ergonomics

H&S through design is a fundamental principle of ergonomics, and the hierarchy of controls is fundamental to the process of hazard reduction i.e. elimination or substitution to mitigate hazards [5]. Although architects and engineers regularly address ergonomics in their designs, their concerns apply almost exclusively to the end-user of a facility, rather than the workers who undertake the construction thereof [5].

2.4. The impact of design on construction ergonomics

Design influences and impacts on construction H&S directly and indirectly. Directly through: concept design; selection of structural frame; detailed design; selection of cladding, and specification of materials. Indirectly through: the selection of procurement system; related interventions such as prequalification; decision regarding project duration, and selection of contractor [6].

A study conducted in the USA to determine whether addressing H&S in the project designs could have prevented incidents, entailed the analysis of 450 reports of construction workers' deaths and disabling injuries [2]. The analysis determined that in 151 cases (33.6%), the hazard that contributed to the incident could have been eliminated or reduced if 'design-for-H&S' measures had been implemented.

2.5. Importance of Health and Safety

Research findings indicate that historically, the traditional project parameters of cost, quality, and time, have taken precedence over H&S, including ergonomics, in terms of the importance of project parameters. During 'The Influence of Architectural Technologists on Construction Ergonomics' study conducted by Smallwood [7], end-user ergonomics, and construction ergonomics were ranked third and seventh respectively in terms of the importance of seven project parameters. Then, construction, commissioning, and deconstruction were ranked third to fifth in terms of the importance of ergonomics during five building / structure phases.

3. Research

3.1. Research method and sample stratum

172 Active design practices in Slovenia constituted the sample stratum. 33 Responses were received and included in the analysis of the data, which equates to a response rate of 19.2%. The analysis of the data consisted of the calculation of descriptive statistics to depict the frequency distribution and central tendency of responses to fixed response questions.

It should be noted that construction ergonomics refers to ergonomics during the phases of construction, commissioning, maintenance, and deconstruction, and end-user ergonomics refers to ergonomics during the use of the building / structure.

A previous study conducted among architectural technologists in South Africa to determine their perceptions and practices with respect to construction ergonomics investigated the: frequency at which construction ergonomics is considered on various occasions and relative to various design related aspects; extent to which various design related aspects impact on construction ergonomics; source of ergonomics knowledge, and the potential of various aspects to contribute to an improvement in construction ergonomics [7]. The study reported on constitutes a replication of this South African study, which study in turn constitutes the origin of the occasions, aspects, and sources.

3.1. Research findings

Table 1 indicates the importance of seven project parameters to respondents in terms of a mean score (MS) ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (not important) to 5 (very important). It is notable that the MSs are all above the midpoint of 3.00, which indicates that in general the respondents perceive the parameters as important. However, given that the MSs for the top four parameters are $> 4.20 \leq 5.00$, the respondents can be deemed to perceive them to be between more than important to very important / very important. It is notable that two of the three traditional project parameters, namely project quality, and project cost are ranked within the top three and project quality first. Project time is ranked fourth. The parameters ranked fifth to seventh have MSs $> 3.40 \leq 4.20$, therefore the respondents can be deemed to perceive them to be between important to more than important / more than important. It is also notable that construction ergonomics, the subject of the study is ranked seventh – last, and after end-user ergonomics.

Table 1. Degree of importance of project parameters to respondents' practices.

Parameter	**Response (%)**					**MS**	**Rank**
	Not…..……Very						
	1	**2**	**3**	**4**	**5**		
Project quality	4,8	0	4,2	23,5	67,5	4,49	1
Project health and safety (H&S)	3.6	1,0	10,2	29,7	55,5	4,33	2
Project cost	2,0	4,0	12,3	29,4	52,3	4,26	3
Project time	4,0	1,0	11,1	35,3	48,6	4,24	4
Environment	2,1	6,3	26,4	38,8	26,4	3,81	5
End-user ergonomics	6,7	5,1	29,4	32,5	26,3	3,67	6
Construction ergonomics	8,2	4,0	36,7	36,7	14,4	3,45	7

Table 2 indicates the importance of ergonomics to respondents during the various project phases in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (not important) to 5 (very important). It is notable that except for deconstruction, the MSs are all above the midpoint of 3.00, which indicates that in general the respondents perceive ergonomics to be important during the related project phases.

No phases fall within the range $> 4.20 \leq 5.00$ - between more than important to very important / very important. Construction, design, use, and maintenance fall within the range $> 3.40 \leq 4.20$ - between important to more than important / more than important. Deconstruction in turn, falls within the range $> 2.60 \leq 3.40$ - between less than important to important / important.

Table 2. Degree of importance of ergonomics during project phases to respondents' practices.

Phase	Response (%) Not…..……Very					MS	Rank
	1	2	3	4	5		
Construction	6,5	4,1	9,6	49,2	30,6	3,93	1
Design	6,8	2,6	20,9	31,0	38,7	3,92	2
Use	6,8	4,0	11,8	38,9	36,2	3,87	3
Maintenance	5,9	7,0	19,7	35,0	32,4	3,81	4
Deconstruction	24,2	15,2	31,0	18,5	11,1	2,77	5

Table 3 presents the frequency at which respondents consider or refer to construction ergonomics on fourteen occasions in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a frequency range of never to always. The project phase within which the occasion falls is referenced between parentheses in terms of stream: upstream (Up); midstream (Mid), and downstream (Down). It is notable that 11 / 14 (78.6%) MSs are above the midpoint of the range, namely 3.00, which indicates the consideration of or reference to construction ergonomics on these occasions can be deemed to be frequent as opposed to infrequent.

It is notable that no occasions fall within the range > 4.20 ≤ 5.00 – between often to always / always. Only 3 / 14 (21.4%) fall within the range > 3.40 ≤ 4.20 – between sometimes to often / often. However, it is also notable that one of the top three occasions is 'midstream', and two are 'upstream'. The remaining occasions fall within the range > 2.60 ≤ 3.40 – between rarely to sometimes / sometimes. A further three 'upstream' occasions are ranked 4th to 6th. 'Upstream' occasions are ideal as it the stage at which construction ergonomics can be mostly influenced.

Table 3. Frequency at which respondents' practices consider or refer to construction ergonomics on various occasions.

Occasion	Response (%) Never	Rarely	Some-times	Often	Always	MS	Rank
Preparing project documentation (Mid)	7,7	5,6	27,2	38,1	21,4	3,60	1
Detailed design (Up)	7,8	6,4	26,7	38,0	21,1	3,58	2
Design (Up)	8,0	7,9	24,0	49,3	10,8	3,47	3
Design coordination meetings (Up)	9,5	8,0	31,5	40,1	10.9	3,35	4
Constructability reviews (Up)	10,8	16,4	24,7	35,2	12,9	3,23	5
Deliberating project duration (Up)	14,1	11,5	24,9	36,4	13,1	3,23	6
Pre-qualifying contractors (Mid)	9,6	16,0	31,9	26,7	15,8	3,23	7
Client meetings (Up)	10,1	12,8	36,5	29,9	10,7	3,18	8
Working drawings (Up)	9,6	16,3	44,1	13,7	16,3	3,11	9
Site handover (Mid)	11,2	19,1	29,4	30,0	10,3	3,09	10
Evaluating tenders (Mid)	10,4	23,6	25,3	30,4	10,3	3,07	11
Site inspections / discussions (Down)	11,4	25,1	33,3	14,8	15,4	2,98	12
Pre-tender meeting (Mid)	11,5	30.1	25,3	22,4	10,7	2,91	13
Site meetings (Down)	13,0	21,1	33,4	26,5	6,0	2,91	14

Table 4 indicates the perceived impact of sixteen design related aspects on construction ergonomics in terms of a MS ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all sixteen MSs are above the midpoint of 3.00, which indicates the respondents perceive the design related aspects to impact on construction ergonomics.

It is notable that no MSs fall within the range of > 4.20 ≤ 5.00 - between a near major to major impact / major impact.

Only four (25%) aspects fall within the range > 3.40 ≤ 4.20, which indicates that they have between an impact and a near major impact / near major impact on construction ergonomics - site location, details, type of structural frame, and design (general). Type of structural frame was identified as the stage that impacts most on construction ergonomics during a study conducted by Smallwood [8].

The remaining 12 / 16 (75%) of aspects' MSs are > 2.60 ≤ 3.40 - between a near minor impact to some impact / some impact on construction ergonomics. Notable rankings include surface area of materials (twelfth), and mass of materials (sixteenth), as these have a major effect in terms of manual handling.

Table 4. Extent to which various design related aspects impact on construction ergonomics.

Aspect	Response (%) Minor……Major					MS	Rank
	1	2	3	4	5		
Site location	10,1	5,2	10,1	41,3	33,3	3,83	1
Details	8,0	3,0	33,2	32,9	22,9	3,60	2
Type of structural frame	8,0	3,0	30,5	40,5	18,0	3,58	3
Design (general)	8,0	8,0	20,7	45,5	17,8	3,57	4
Position of components	10,2	5,2	38,4	32,9	13,3	3,34	5
Finishes	8,0	10,0	36,3	33,0	12,7	3,32	6
Plan layout	10,0	13,0	33,4	22,8	20,8	3,31	7
Method of fixing	12,7	8,1	40,8	12,7	25,7	3,31	8
Content of material	9,6	0,0	50,4	31,9	8,1	3,29	9
Elevations	8,0	12,7	44,2	14,6	20,5	3,27	10
Texture of materials	10,1	8,0	46,3	25,7	9,9	3,17	11
Surface area of materials	9,9	8,1	43,5	33,4	5,1	3,16	12
Edge of materials	7,9	9,8	45,8	31,4	5,1	3,16	13
Schedule	12,6	20,8	25,8	22,7	18,1	3,13	14
Specification	8,0	22,5	29,5	30,5	9,5	3,11	15
Mass of materials	12,2	8,0	50,2	24,9	4,7	3,02	16

Table 5 presents the frequency at which respondents consider / refer to construction ergonomics relative to sixteen design related aspects, in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a frequency range of never to always. It is notable that all sixteen MSs are above the midpoint of 3.00, which indicates consideration of / reference to H&S relative to these design related aspects can be deemed to be frequent as opposed to infrequent.

It is notable that no occasions fall within the range $> 4.20 \leq 5.00$ – between often to always / always, and similarly within the range $> 3.40 \leq 4.20$ – between sometimes to often / often.

All the aspects fall within the range $> 2.60 \leq 3.40$ – between rarely to sometimes / sometimes. Site location, method of fixing, and details predominate, and are ranked in the top three. They are followed by specification, and type of structural frame, the latter being notable as it is the stage that impacts most on construction ergonomics (Smallwood, 2002). Along with design (general) ranked eighth it provides the framework for a project in terms of construction ergonomics. Given that certain materials contain hazardous chemical substances it is notable that content of material achieved a ranking of thirteenth. Furthermore, given that materials handling, and more specifically the mass of materials contributes to manual materials handling, it is also notable that mass of materials has a MS marginally above the midpoint of 3.00 (3.04), and was ranked eleventh. Similarly, given that the surface area of many materials required for certain elements such as gypsum boards for ceilings and partitions, and glazing for shop fronts is large, the MS of 3.01 is notable. However, it should be noted that finishes and schedule, which encapsulate materials and processes, achieved rankings of seventh and ninth respectively.

Table 5. Frequency at which respondents' practices consider or refer to construction ergonomics relative to various design related aspects.

Aspect	Response (%) Never	Rarely	Some-times	Often	Always	MS	Rank
Site location	10,7	12,8	20,4	39,0	17,1	3,39	1
Method of fixing	22,2	9,1	36,4	21,5	10,8	3,39	2
Details	11,0	11,0	23,9	41,3	12,8	3,34	3
Specification	8,7	15,1	33,0	30,3	12,9	3,24	4
Type of structural frame	10,9	15,6	27,2	33,1	13,2	3,22	5
Plan layout	9,0	15,1	32,7	32,6	10,6	3,21	6
Finishes	13,1	11,3	27,1	39,1	9,4	3,20	7
Design (general)	11,0	13,2	37,3	29,7	8,8	3,12	8
Schedule	15,4	13,3	30,2	28,2	12,9	3,10	9
Elevations	19,5	13,0	24,4	29,9	13,2	3,04	10
Mass of materials	12,9	19,7	32,5	20,1	14,8	3,04	11
Edge of materials	15,1	10,7	37,3	30,1	6,8	3,03	12
Texture of materials	13,5	13,5	39,5	24,8	8,7	3,02	13
Content of material	15,1	10,6	41,2	24,1	9,0	3,01	14
Surface area of materials	14,9	7,0	47,5	23,6	7,0	3,01	15
Position of components	14,8	12,7	33,1	35,4	4,0	3,01	16

Respondents were required to indicate their knowledge of 'ergonomics' in terms of percentage responses to a scale of 1 (limited) to 5 (extensive). The resultant MS of 2.77 is > 2.60 ≤ 3.40, whichindicates the knowledge can be deemed to be between less than average to average / average. However, 2.77 falls marginally above the lower range > 1.80 ≤ 2.60 - between limited to less than average / less than average.

Table 7 indicates that experience (75.8%) predominates in terms of respondents' source of ergonomics knowledge, followed by experience (51.5%) and magazine articles (36.4%). The remaining resources attracted less than a third response.

Table 7. Respondents' source of ergonomics knowledge.

Source	Yes (%)
Practice notes	75.8
Experience	51.5
Magazine articles	36.4
Journal papers	24.2
Conference papers	21.2
Workshops	18.2
Tertiary education	15.2
Other	6.1
Post graduate qualifications	6.1
CPD seminars	3.0

Table 8 indicates the potential of various aspects / interventions to contribute to an improvement in construction ergonomics during the various project phases in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (minor) to 5 (major). The letters inserted within parentheses denote whether the aspect / intervention is design (D), procurement (P), construction (C), or multi-phase related. It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents perceive the various aspects / interventions to have the potential to contribute to an improvement in construction ergonomics during the various project phases.

General design, awareness, and contractor planning predominate, and their MSs are > 3.40 ≤ 4.20 – between potential to near major potential / near major potential to contribute. It is notable that the top ranked aspect / intervention is design phase related, the second construction and design, the third, construction, related, and that the fourth and fifth aspects / interventions, details and constructability (general), are design related.

Table 8. Potential of various aspects / interventions to contribute to an improvement in construction ergonomics during the various project phases.

Aspect / intervention	Response (%) Minor……Major					MS	Rank
	1	2	3	4	5		
General design (D)	6,0	0,0	19,4	42,3	32,3	3,95	1
Awareness (C & D)	10,0	0,0	23,3	31,6	35,1	3,82	2
Contractor planning (C)	6,1	3,0	23,2	44,6	23,1	3,76	3
Details (D)	6,0	0,0	39,1	39,1	15,8	3,59	4
Constructability (general) (D)	6,1	3,3	35,2	39,3	16,1	3,56	5
Design of equipment (construction) (C)	6,1	3,1	39,3	45,3	6,2	3,42	6
Safe working procedures (C)	10,0	12,9	23,0	34,7	19,4	3,41	7
Reengineering (C, D & P)	6,2	6,2	36,0	45,4	6,2	3,39	8
Mechanisation (C & D)	6,1	10,3	31,9	45,5	6,2	3,35	9
Design of tools (construction) (C)	6,0	13,3	39,0	28,6	13,1	3,30	10
Workshops on site (C)	10,0	12,8	25,7	41,5	10,0	3,29	11
Prefabrication (D)	6,2	13,3	42,1	25,2	13,2	3,26	12
Specification (general) (D)	6,1	19,4	32,3	36,1	6,1	3,17	13

79.2% of Respondents were familiar with the Slovenian 'Health and Safety Work Act' and 20.8% were not. 55.9% were familiar with the ergonomic provisions of the construction and design regulations related to their work, and 44.1% were not.

4. Conclusions

The traditional project parameters of quality, cost and time are more important than construction ergonomics to designers. However, project H&S was ranked second. Therefore, it can be concluded that designers do not understand and appreciate the synergy between project H&S and ergonomics, and the other parameters.

Construction ergonomics is more important during the construction and design stages than the use, maintenance, and commissioning phases, and therefore the focus is likely to be more on the former than the latter phases.

Designers do consider construction ergonomics on various occasions, however, more so during upstream phases than mid-stream phases, design included. Therefore, it can be concluded that the cited importance thereof does manifest itself. However, the frequency is mostly between rarely to sometimes / sometimes.

Designers consider construction ergonomics on various design related occasions. However, the frequency is mostly between rarely to sometimes / sometimes. The frequency relative to mass of materials is notable and is possibly attributable to a lack of knowledge of the mass of materials.

Designers do appreciate the extent to which various design related aspects impact on construction ergonomics to a degree in that they maintain most design related aspects have between a near minor impact to some impact / some impact thereon.

Furthermore, given the divergent rankings between the perceived impact of design related aspects on construction ergonomics, and the consideration / reference to such aspects, it can be concluded that designers' actions are not always based on a structured process such as documented design hazard identification and risk assessment.

Given the sources of architectural technologists' ergonomics knowledge it can be concluded that the sources are more informal than formal – practice notes, experience, and magazine articles, vis-à-vis tertiary education. It can also be concluded that tertiary designer education and the design professions are not addressing ergonomics to the extent that they should. These conclusions are reinforced by the designers' 'below average' self-rating of their knowledge of ergonomics.

Given the perceived potential of various aspects / interventions to contribute to an improvement in construction ergonomics, it can be concluded that designers, to a degree, do appreciate the potential of various design, procurement and construction practices to contribute to an improvement in construction ergonomics.

5. Recommendations

Designers' tertiary education should address construction H&S and ergonomics, and highlight the role thereof in overall project performance. Furthermore, designing for construction H&S and ergonomics should be introduced and more importantly, embedded in designer tertiary education programmes.

Designer professional associations / institutions should evolve construction H&S and ergonomics practice notes, and promote continuing professional development (CPD relative to construction H&S and ergonomics.

References

[1] Commission of the European Communities, Four guides for the 'temporary or mobile construction sites' directive, Brussels: Office for Official Publications of the European Communities, 1993.
[2] M. Behm, An Analysis of Construction Accidents from a Design Perspective, Silver Spring: The Center to Protect Workers' Rights, 2006.
[3] B. Thorpe, Health and Safety in Construction Design, Aldershot: Gower Publishing Limited, 2006.
[4] International Labour Office (ILO) 1992, Safety and health in construction, ILO, Geneva.
[5] S. F. Hecker, J. A. Gambatese, M. Weinstein, Designing for construction safety in the US: Progress, needs, and future directions, In: Proceedings of the 16th Triennial Congress of the International Ergonomics Association, Maastricht, The Netherlands, 10-14 July, D:\data\pdfs\art0563.pdf, 2006.
[6] J.J. Smallwood, The influence of engineering designers on health and safety during construction, Journal of the South African Institution of Civil Engineering. 46(1) (2004) 2–8.
[7] J. J. Smallwood, J.J., The Influence of Architectural Technologists on Construction Ergonomics, GSTF Journal of Engineering Technology (JET). 4(3) (2017) 147-154.
[8] J.J. Smallwood, Construction Ergonomics: General Contractor (GC) Perceptions, ergonomics SA. 14(1) 92002) 8-18.