

Figure 1: Overall research design for the study

Table 1: Key factors affecting the SSP implementation. Adapted from Olawumi and Chan (2020c).

| **Code** | **Key drivers** | **References** |
| --- | --- | --- |
| D1 | Technical competence of staff | Gu and London (2010); Tsai et al. (2014); Deutsch (2011)  |
| D2 | Greater awareness and experience level within the firm | Chan (2014); Kassem et al. (2012)  |
| D3 | More training programs for cross-field specialists in BIM and Sustainability | Wong and Fan (2013); Jalaei and Jrade (2014)  |
| D4 | Increased research in the industry and academia | Abdirad (2016); Bolgani (2013) |
| D5 | Government establishment of start-up funding for construction firms to kick-start BIM initiatives | Abubakar et al. (2014) |
| D6 | Adequate construction cost allocated to BIM | Gu and London (2010); Kivits and Furneaux (2013) |
| D7 | Availability of financial resources for BIM software, licenses, and its regular upgrades | Nanajkar and Gao (2014) |
| D8 | Information and knowledge-sharing within the industry | Azhar (2011); Chan et al. (2019b)  |
| D9 | Effective collaboration and coordination among project participants | Antón and Díaz (2014); Hanna et al. (2014) |
| D10 | Establishment of a model of good practice for BIM and sustainability execution | Antón and Díaz (2014); Adamus (2013) |
| D11 | Availability and a well-managed in-house database of information on similar projects | Aibinu and Venkatesh (2014); Becerik-gerber and Kensek (2010) |
| D12 | Development of appropriate legal framework for BIM use and deployment in projects | Aibinu and Venkatesh (2014); Azhar (2011) |
| D13 | Security of intellectual property and rights | Kivits and Furneaux (2013) |
| D14 | Shared risks, liability, and rewards among project stakeholders | Chan (2014); Park et al. (2013) |
| D15 | Establishment of BIM standards, codes, rules, and regulations | Redmond et al. (2012) |
| D16 | Appropriate legislation and governmental enforcement & credit for innovative performance | Antón and Díaz (2014); Hope and Alwan (2012) |
| D17 | Increased involvement of project stakeholders in green projects | Alsayyar and Jrade (2015) |
| D18 | Clarity in requirements and measures for achieving sustainable projects | Aibinu and Venkatesh (2014) |
| D19 | Number of subcontractors experienced with BIM projects” | Chan (2014) |
| D20 | Client requirement and ownership | Ahn et al. (2014); Chan et al. (2019a) |
| D21 | Early involvement of project teams | Kassem et al. (2012) |
| D22 | Client satisfaction level on BIM projects | Ahn et al. (2014); Chan (2014) |
| D23 | Supportive organizational culture and effective leadership | Yeomans et al. (2006) |
| D24 | Project complexity (regarding building shape or building systems) | Hope and Alwan (2012); Kivits and Furneaux (2013) |
| D25 | Availability and affordability of cloud-based technology | Ahn et al. (2014); Yeomans et al. (2006) |
| D26 | Interoperability and data compatibility | Adamus (2013); Saxon (2013) |
| D27 | Standardization & simplicity of BIM and sustainability assessment software | Akinade et al. (2017); Aksamija (2012) |
| D28 | Technical support from software vendors | Redmond et al. (2012) |
| D29 | Availability of BIM and sustainability databases | Abolghasemzadeh (2013); Antón and Díaz (2014)  |
| D30 | Open-source software development | Hope and Alwan (2012) |

Table 2: Demographics of survey respondents

| **Characteristics** | **Nigeria** | **Hong Kong** |
| --- | --- | --- |
| **Percentage (size)** | **Percentage (size)** |
| **Years of working experience**< 5years5-10 years11-15 years16-20 years> 20 years | 33.3% (23)33.3% (23)10.1% (7)10.1% (7)13.0% (9) | 32% (31)21% (20)8% (8)8% (8)31% (30) |
| **Type of organization**Public ClientPrivate ClientProject ConsultantMain ContractorProperty Management CompanyAcademic Institution | 8.7% (6)8.7% (6)18.8% (13)13.0% (9) 1.4% (1)49.3% (34) | 39.2% (38)5.2% (5)9.3% (9)24.7% (24)5.2% (5)16.5% (16) |
| **Level of awareness of sustainability practices**Very HighHighAverageLowVery Low | 15.9% (11)52.1% (36)28.9% (20)2.8% (2)0% (0) | 8.2% (8)26.8% (26)44.3% (43)13.4% (13)7.2% (7) |
| **Level of awareness of BIM process**Very HighHighAverageLowVery Low | 13% (9)34.7% (24)39.1% (27)11.5% (8)1.4% (1) | 7.2% (7)20.6% (20)41.2% (40)14.4% (14)16.4% (16) |
| **When best to implement smart sustainable practices?**Planning stageDesign stageConstruction stageFacility management stage | 66.6% (46)31.8% (22)1.4% (1)0% (0) | 42.2% (41)47.4% (46)9.2% (9)1% (1) |

Table 3: Ranking of the drivers for smart sustainable practices implementation in Nigeria and Hong Kong

| **Nigeria** | **Hong Kong** |
| --- | --- |
| **Drivers** | **MS** | **SD** | **Rank**  | $$N\_{m}$$ | **Drivers** | **MS** | **SD** | **Rank**  | $$N\_{m}$$ |
| D1 | 4.54 | .655 | 1 | 1.000 | D1 | 4.12 | .869 | 1 | 1.000 |
| D3 | 4.46 | .655 | 2 | .886 | D2 | 4.02 | .816 | 2 | .825 |
| D21 | 4.46 | .677 | 3 | .886 | D3 | 4.00 | .791 | 3 | .789 |
| D2 | 4.42 | .651 | 4 | .818 | D15 | 3.99 | .823 | 4 | .772 |
| D9 | 4.41 | .734 | 5 | .795 | D27 | 3.98 | .777 | 5 | .754 |
| D4 | 4.35 | .744 | 6 | .705 | D21 | 3.94 | .911 | 6 | .684 |
| D23 | 4.30 | .692 | 7 | .636 | D28 | 3.90 | .835 | 7 | .614 |
| D17 | 4.30 | .713 | 8 | .636 | D10 | 3.88 | .781 | 8 | .579 |
| D15 | 4.30 | .734 | 9 | .636 | D22 | 3.87 | .799 | 9 | .561 |
| D10 | 4.30 | .792 | 10 | .636 | D29 | 3.87 | .824 | 10 | .561 |
| D18 | 4.28 | .705 | 11 | .591 | D24 | 3.87 | .824 | 11 | .561 |
| D8 | 4.28 | .765 | 12 | .591 | D23 | 3.86 | .790 | 12 | .544 |
| D26 | 4.28 | .820 | 13 | .591 | D7 | 3.86 | .804 | 13 | .544 |
| D29 | 4.26 | .902 | 14 | .568 | D6 | 3.86 | .901 | 14 | .544 |
| D22 | 4.25 | .793 | 15 | .545 | D5 | 3.85 | .846 | **15** | **.526** |
| D16 | 4.25 | .812 | **16** | **.545** | D18 | 3.82 | .736 | 16 | .491 |
| D12\* | 4.22 | .820 | 17 | .500 | D9 | 3.82 | .764 | 17 | .491 |
| D25\* | 4.22 | .838 | 18 | .500 | D11 | 3.80 | .786 | 18 | .456 |
| D11 | 4.20 | .778 | 19 | .477 | D16 | 3.79 | .803 | 19 | .439 |
| D7 | 4.19 | .896 | 20 | .455 | D8 | 3.79 | .816 | 20 | .439 |
| D27 | 4.17 | .857 | 21 | .432 | D30 | 3.78 | .807 | 21 | .421 |
| D20 | 4.16 | .933 | 22 | .409 | D4 | 3.77 | .810 | 22 | .404 |
| D5 | 4.13 | 1.028 | 23 | .364 | D20 | 3.77 | .848 | 23 | .404 |
| D14 | 4.12 | .718 | 24 | .341 | D19 | 3.76 | .801 | 24 | .386 |
| D13 | 4.07 | .846 | 25 | .273 | D17 | 3.76 | .826 | 25 | .386 |
| D28 | 4.07 | .846 | 25 | .273 | D12 | 3.75 | .791 | 26 | .368 |
| D19 | 4.06 | .838 | 27 | .250 | D26 | 3.75 | .817 | 27 | .368 |
| D24 | 4.06 | 1.013 | 28 | .250 | D14 | 3.70 | .915 | 28 | .281 |
| D30 | 4.04 | .992 | 29 | .227 | D13 | 3.64 | .844 | 29 | .175 |
| D6 | 3.90 | 1.002 | 30 | .000 | D25 | 3.54 | .890 | 30 | .000 |

*NB: \*drivers which correlate (at p<0.05) were removed from subsequent analysis.*

Table 4: Factor structure for the key drivers (Nigeria context)

| **Key drivers** | **Factor loadings** | **Eigenvalue** | **% of variance explained** | **Cumulative % of variance explained** |
| --- | --- | --- | --- | --- |
| **DG1 – Knowledge & Enforcement** |  | 7.399 | 46.243 | 46.243 |
| D10 - Establishment of a model of good practice for BIM and sustainability implementation | 0.811 |  |  |  |
| D1 - Technical competence of staff | 0.746 |  |  |  |
| D3 - More training programs for cross-field specialists in BIM and Sustainability | 0.629 |  |  |  |
| D16 - Appropriate legislation and governmental enforcement & credit for innovative performance | 0.609 |  |  |  |
| **DG2 – Effective partnership** |  | 1.488 | 9.298 | 55.540 |
| D18 - Clarity in requirements and measures for achieving sustainable projects | 0.740 |  |  |  |
| D23 - Supportive organizational culture and effective leadership | 0.735 |  |  |  |
| D17 - Increased involvement of project stakeholders in green projects | 0.657 |  |  |  |
| D9 - Effective collaboration and coordination among project participants | 0.598 |  |  |  |
| D2 - Greater awareness and experience level within the firm | 0.558 |  |  |  |
| D8 - Information and knowledge-sharing within the industry | 0.537 |  |  |  |
| **DG3 – Technical specifications** |  | 1.235 | 7.719 | 63.260 |
| D26 - Interoperability and data compatibility | 0.778 |  |  |  |
| D29 - Availability of BIM and sustainability databases | 0.745 |  |  |  |
| D15 - Establishment of BIM standards, codes, rules, and regulations | 0.724 |  |  |  |
| **DG4 – Collaboration and Value** |  | 1.061 | 6.631 | **69.890** |
| D22 - Client satisfaction level on BIM projects | 0.844 |  |  |  |
| D21 - Early involvement of project teams | 0.700 |  |  |  |
| D4 - Increased research in the industry and academia | 0.541 |  |  |  |

Table 5: Factor structure for the key drivers (Hong Kong context)

| **Key drivers** | **Factor loadings** | **Eigenvalue** | **% of variance explained** | **Cumulative % of variance explained** |
| --- | --- | --- | --- | --- |
| **DDG1 – Knowledge**  |  | 9.804 | 65.358 | 65.358 |
| D3 - More training programs for cross-field specialists in BIM and Sustainability | 0.748 |  |  |  |
| D2 - - Greater awareness and experience level within the firm | 0.711 |  |  |  |
| D23 - Supportive organizational culture and effective leadership | 0.571 |  |  |  |
| D1 - Technical competence of staff | 0.543 |  |  |  |
| **DDG2 – Technical specifications** |  | 1.011 | 6.740 | 72.098 |
| D10 - Establishment of a model of good practice for BIM and sustainability implementation | 0.718 |  |  |  |
| D28 - Technical support from software vendors | 0.654 |  |  |  |
| D15 - Establishment of BIM standards, codes, rules, and regulations | 0.650 |  |  |  |
| D29 - Availability of BIM and sustainability databases | 0.594 |  |  |  |
| **DDG3 – Project performance & collaboration** |  | 0.823 | 5.490 | 77.588 |
| D24 - Project complexity (regarding building shape or building systems) | 0.809 |  |  |  |
| D21 - Early involvement of project teams | 0.707 |  |  |  |
| D22 - Client satisfaction level on BIM projects | 0.651 |  |  |  |
| D27 - Standardization & simplicity of BIM and sustainability assessment software | 0.583 |  |  |  |
| **DDG4 – Finance/Cost** |  | 0.511 | 3.407 | **80.995** |
| D6 - Adequate construction cost allocated to BIM | 0.885 |  |  |  |
| D7 - Availability of financial resources for BIM software, licenses, and its regular upgrades | 0.795 |  |  |  |
| D5 - Government establishment of start-up funding for construction firms to kick-start BIM initiatives | 0.652 |  |  |  |

Table 6: Weightings for the Ds and DGs for smart sustainable practices implementation

| **Nigeria** | **Hong Kong** |
| --- | --- |
| **Drivers** | $$MS\_{d}$$ | $$W\_{DG}$$ | $$MS\_{dg}$$ | $$W\_{DG}$$ | **Drivers** | $$MS\_{d}$$ | $$W\_{DG}$$ | $$MS\_{ddg}$$ | $$W\_{DDG}$$ |
| D10 | 4.30 | 0.245 |  |  | D3 | 4.00 | 0.250 |  |  |
| D1 | 4.54 | 0.259 |  |  | D2 | 4.02 | 0.251 |  |  |
| D3 | 4.46 | 0.254 |  |  | D23 | 3.86 | 0.241 |  |  |
| D16 | 4.25 | 0.242 |  |  | D1 | 4.12 | 0.258 |  |  |
| **DG1 – Knowledge & Enforcement** | 17.55 | 0.253 | **DDG1 – Knowledge** | 16.00 | 0.272 |
| D18 | 4.28 | 0.165 |  |  | D10 | 3.88 | 0.248 |  |  |
| D23 | 4.30 | 0.165 |  |  | D28 | 3.90 | 0.249 |  |  |
| D17 | 4.30 | 0.165 |  |  | D15 | 3.99 | 0.255 |  |  |
| D9 | 4.41 | 0.170 |  |  | D29 | 3.87 | 0.247 |  |  |
| D2 | 4.42 | 0.170 |  |  | **DDG2 – Technical specifications** | 15.64 | 0.266 |
| D8 | 4.28 | 0.165 |  |  |  |  |  |  |  |
| **DG12– Effective partnership** | 25.99 | 0.374 | D24 | 3.87 | 0.247 |  |  |
| D26 | 4.28 | 0.333 |  |  | D21 | 3.94 | 0.252 |  |  |
| D29 | 4.26 | 0.332 |  |  | D22 | 3.87 | 0.247 |  |  |
| D15 | 4.30 | 0.335 |  |  | D27 | 3.98 | 0.254 |  |  |
| **DG3 – Technical specifications** | 12.84 | 0.185 | **DDG3 – Project performance & collaboration** | 15.66 | 0.266 |
| D22 | 4.25 | 0.325 |  |  | D6 | 3.86 | 0.334 |  |  |
| D21 | 4.46 | 0.342 |  |  | D7 | 3.86 | 0.334 |  |  |
| D4 | 4.35 | 0.333 |  |  | D5 | 3.85 | 0.333 |  |  |
| **DG4 – Collaboration and Value** | 13.06 | 0.188 | **DDG4 – Finance/Cost** | 11.57 | 0.197 |
|  |  |  |  |  |  |  |  |
| **Total Mean for the Groupings** | **69.44** |  | **Total Mean for the Groupings** | **58.87** |  |

$MS\_{d}$= mean score for drivers; $MS\_{dg}$ / $MS\_{ddg}$= Total mean score for each driver groupings

$W\_{D}$ = Weightings for each driver; $W\_{DG}$ / $W\_{DDG}$ = Weightings for each driver groupings

Table 7: Membership functions for all Ds and DGs/DDGs

| **Key drivers and Drivers’ groupings** | **Weightings for the Ds** | **Membership function at Level 2 (Ds)** | **Membership function at Level 1 (DGs/DDGs)** |
| --- | --- | --- | --- |
| **Hong Kong context** |
| **DDG1 – Knowledge** |  | 0.02 | 0.01 | 0.16 | 0.54 | 0.26 |
| D3 | *0.250* | 0.02 | 0.01 | 0.15 | 0.58 | 0.24 |  |  |  |  |  |
| D2 | *0.251* | 0.02 | 0.02 | 0.13 | 0.57 | 0.26 |  |  |  |  |  |
| D23 | *0.241* | 0.02 | 0.02 | 0.21 | 0.59 | 0.16 |  |  |  |  |  |
| D1 | *0.258* | 0.02 | 0.01 | 0.17 | 0.43 | 0.37 |  |  |  |  |  |
| **DDG2 – Technical specifications** | 0.02 | 0.01 | 0.19 | 0.57 | 0.20 |
| D10 | *0.248* | 0.02 | 0.01 | 0.22 | 0.58 | 0.17 |  |  |  |  |  |
| D28 | *0.249* | 0.03 | 0.02 | 0.15 | 0.61 | 0.19 |  |  |  |  |  |
| D15 | *0.255* | 0.02 | 0.01 | 0.19 | 0.52 | 0.26 |  |  |  |  |  |
| D29 | *0.247* | 0.03 | 0.01 | 0.20 | 0.59 | 0.17 |  |  |  |  |  |
| **DDG3 – Project performance & collaboration** | 0.02 | 0.02 | 0.18 | 0.56 | 0.22 |
| D24 | *0.247* | 0.02 | 0.03 | 0.19 | 0.57 | 0.19 |  |  |  |  |  |
| D21 | *0.252* | 0.03 | 0.03 | 0.16 | 0.52 | 0.26 |  |  |  |  |  |
| D22 | *0.247* | 0.02 | 0.01 | 0.24 | 0.54 | 0.19 |  |  |  |  |  |
| D27 | *0.254* | 0.02 | 0.01 | 0.15 | 0.60 | 0.22 |  |  |  |  |  |
| **DDG4 – Finance/Cost** |  | 0.02 | 0.03 | 0.23 | 0.52 | 0.21 |
| D6 | *0.334* | 0.02 | 0.06 | 0.17 | 0.53 | 0.22 |  |  |  |  |  |
| D7 | *0.334* | 0.02 | 0.01 | 0.25 | 0.53 | 0.19 |  |  |  |  |  |
| D5 | *0.333* | 0.02 | 0.02 | 0.26 | 0.49 | 0.21 |  |  |  |  |  |
| **Nigeria context** |
| **DG1 – Knowledge & Enforcement** |  |  | 0.00 | 0.02 | 0.07 | 0.39 | 0.51 |
| D10 | *0.245* | 0.01 | 0.00 | 0.12 | 0.41 | 0.46 |  |  |  |  |  |
| D1 | *0.259* | 0.00 | 0.02 | 0.04 | 0.33 | 0.61 |  |  |  |  |  |
| D3 | *0.254* | 0.00 | 0.01 | 0.04 | 0.41 | 0.54 |  |  |  |  |  |
| D16 | *0.242* | 0.00 | 0.04 | 0.10 | 0.42 | 0.44 |  |  |  |  |  |
| **DG2 – Effective partnership** |  |  |  |  |  |  | 0.00 | 0.01 | 0.07 | 0.46 | 0.45 |
| D18 | *0.165* | 0.00 | 0.01 | 0.10 | 0.48 | 0.41 |  |  |  |  |  |
| D23 | *0.165* | 0.00 | 0.01 | 0.09 | 0.48 | 0.42 |  |  |  |  |  |
| D17 | *0.165* | 0.00 | 0.01 | 0.10 | 0.45 | 0.44 |  |  |  |  |  |
| D9 | *0.170* | 0.01 | 0.00 | 0.06 | 0.42 | 0.51 |  |  |  |  |  |
| D2 | *0.170* | 0.00 | 0.03 | 0.00 | 0.49 | 0.48 |  |  |  |  |  |
| D8 | *0.165* | 0.02 | 0.00 | 0.10 | 0.46 | 0.42 |  |  |  |  |  |
| **DG3 – Technical specifications** |  |  |  | 0.01 | 0.02 | 0.09 | 0.43 | 0.45 |
| D26 | *0.333* | 0.01 | 0.02 | 0.10 | 0.42 | 0.45 |  |  |  |  |  |
| D29 | *0.332* | 0.03 | 0.03 | 0.04 | 0.45 | 0.45 |  |  |  |  |  |
| D15 | *0.335* | 0.00 | 0.01 | 0.12 | 0.42 | 0.45 |  |  |  |  |  |
| **DG4 – Collaboration and Value** |  |  | 0.00 | 0.02 | 0.09 | 0.40 | 0.49 |
| D22 | *0.325* | 0.00 | 0.04 | 0.09 | 0.45 | 0.42 |  |  |  |  |  |
| D21 | *0.342* | 0.00 | 0.01 | 0.06 | 0.38 | 0.55 |  |  |  |  |  |
| D4 | *0.333* | 0.00 | 0.01 | 0.12 | 0.38 | 0.49 |  |  |  |  |  |

Table 8: PEM index for DGs/DDGs for smart sustainable practices implementation

|  |  |  |
| --- | --- | --- |
| **Driver groupings** | **PEM index (**$PEM\_{i}$**)** | **Coefficientsy** |
|  **Hong Kong context** |
| DDG1 – Knowledge | 4.00 | 0.255 |
| DDG2 – Technical specifications | 3.91 | 0.249 |
| DDG3 – Project performance & collaboration | 3.92 | 0.250 |
| DDG4 – Finance/Cost | 3.86 | 0.246 |
| **Total** | **15.70** | **1.000** |
|  **Nigeria context** |
| DG1 – Knowledge & Enforcement | 4.40 | 0.253 |
| DG2 – Effective partnership | 4.34 | 0.250 |
| DG3 – Technical specifications | 4.28 | 0.246 |
| DG4 – Collaboration and Value | 4.36 | 0.251 |
| **Total** | **17.38** | **1.00** |

 $= \left(^{PEM\_{i} for DDG/DG}/\_{\sum\_{}^{}PII for DDG/DG}\right)$