

# Advancements in Sustainable and Innovative Technologies for Complex Systems

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**Abstract** 7KLVSDSHUVXPPDUL]HVVRPHRIWKHGLVFXVVL  
RQVWKDW  
RFFXUUHG LQ D ZRUNVKRS LQ :HVW 9LUJLQLD 86\$  
ZKLFK ZDV VSRQVRUHG E\ WKH 1DWLRQDO 6FLHQFH  
)RXQGDLRQ16) LQ )HEUXDU\  
7KHJRDORIWKHZRUNVKRSZDVWRH[SORUHWKHRSSRU  
WXQLWLHVDQG  
FKDOOHQJHVIRUDSSO\LQJV\VVWHPVHQJLQHHULQJLQOD  
UJHHQWHUSULVHVDQG  
VRPHRIWKHLVXHVWKDWVWLOOSHUVLVW7KHPDLQ  
WRSFLVRIWKHGLVFXVVLQ  
LQFOXGHGFKDOOHQJHVZLWKHODERUDWLRQDQGDEV  
WUDFWLRQLQODUJHV\VVWHPV  
LQWHUIDFLQJ\SK\VLFDODQGVRLDOV\VVWHPVDQGWKH  
QHHGIRUD[LRPDWLF  
IUDPHZRUNVIRUODUJHHQWHUSULVHV:HVXPPDUL]HW  
KHVHPDLQSRQLQWVRI  
GLVFXVVLQGDZLQJSDUDOOHOVZLWKGHFLVLRQPD  
NLQJLQRUJDQL]DWLRQVWR  
LQVWLJDWHUHVHDFLQWKHVHGLVFXVVLQDUHDV

**Keywords** HFLVLRQ DQDO\VLV \VVWHPV  
HQJLQHHULQJ IUDPLQJ YDOXHFDUHDWLRQ

..1752'8&7,21:+\$7+2:;<"

+(SXUSRVHRIWKLVSDSHULVWRUHOHFWRQWKHRS  
RUWXQLWLHV  
DQG FKDOOHQJHV WKDW OD\ DKHDG LQ WKH  
ILHOG RI \VVWHPV  
HQJLQHHULQJIRFXVLQJRQDZRUNVKRSWKDWZDVVS  
RQVRUHGE\  
WKH861DWLRQDO6FLHQFH)RXQGDLRQ16)7KHZRU  
NVKRS VWDUWHG ZLWK D GLVFXVVLQ DERXW  
WKH "KDW" +RZ" :K\ RI \VVWHPV HQJLQHHULQJ  
7KHUH DUH PDQ\ GHILQLWLRQV RI \VVWHPV  
HQJLQHHULQJQDQGWKHSXUSRVHRIWKHULVQRWRSU  
RYLGHDXQLNLQJ  
GHILQLWLRQDQGWKHSXUSRVHGGHILQLWLRQWKD  
WZLOOEHFRQVLGHUHG  
LQWKLVSDSHU\VVWHPVHQJLQHHULQJLVXOWLPDW  
HODERXWGHULYLQJ YDOXH IURP D JLYHQ  
SKHQRPHQRQ ZLWKLQ WKH FRQWH[RW RI D \VVWHP  
RI VXE\VVWHPV ,QGHG ZKDW ZH GR LQ \VVWHPV  
DQDO\VLVWVWUWVZLWKWKHLQYHVWLJDWLRQRIV  
RPHSKHQRPHQRQWKDW  
FRXOGEHURRWHLQPDQ\ILHOGVLQFOXGLQJPHGLF  
DOHOHFWULFDQ  
SK\VLFDORUHYHQDFRQJLWLYHEHKDYLRUDODQGW  
KHSXUSRVHVLVWR  
GHULYHYDOXHRIURPWKLVSKHQRPHQRQ,QDODUJHH

QWHUSULVHZZ DUH GHDOLQJ ZLWK PXOWLSOH  
SHRSOH DQG PXOWLSOH VXE\VVWHPV DQG  
LQWHUGLVFLSOLQDU\ DUHDV WKDW LQWHUIDFH  
ZLWK HDFK RWKHU DW FHUWDLQERXQGDULHV  
7KH QH[W TXHVWLRQ LV "K" 7KLV LV DQ HDV\  
TXHVWLRQ EDVHG RQ RXU SUHYLRXV GHILQLWLRQ  
WR GHULYH YDOXH ,QGHG  
HYHUERG\ DJUHHV WKDW \VVWHPV HQJLQHHULQJ  
SURYLGHV PDQ\ RSSRUWXQLWLHV IRU WKH GHVLQJ  
RI ODUJH VFDOH \VVWHPV ORVW  
SHRSOHDVNWKLVTXHVWLRQKRZHYHULQWHUPVRI  
ZK\GRZHQHHG WR FKDQJH IURP WKH FXUUHQW  
\VVWHP" :K\ LV WKH FXUUHQW  
DSSURDFKQRWDGHTXDWH"7KHDQVZHUWRVRPHRI  
WKHVHTXHVWLRQV  
ZLOOEHGLVFXVVLQGLQWKLVSDSHU  
7KHWKHUTXHVWLRQLVWRZV\VVWHPVHQJLQHHU  
LQJFDQSURYLGH  
YDOXHLQJLQHHULQJWHUSULVH"\$QGWKHDQVZHU  
WKURXJKDVHW  
RIWRROVSURFHVVHVQHZWKHRULHVDQGDORJLFW  
KDWHQDEOHVD

(\$EEDVLVZLWKWKHGHSDUWPHQWRI,QGXVWULDODQGVVWH  
PV(QJLQHHULQJDQ  
3XEOLF3ROLF\DWK8QLYHUVLW\RI6RXWKHUQ&DOLIRUQLD  
/RV\$QHOHV&\$H  
PDLQDQDEEDV#XVFGX

## A. Abstraction and Elaboration

%HFDXVZHHDUHGHDOLQJZLWKDODUJHV\VVWHPD  
PDMRUSDUWRI WKH ZRUNVKRS FRQVLGHUHG  
DEVWUDFWLRQ DQG HODERUDWLRQ RI YDULRXV  
VXE\VVWHPV ZKDW LV ZK\ ZH ZLOO EH  
HPSKDV[LQJ DQG ZKDW ZH ZLOO EH  
GHHPKDV[LQJ LQ WKH DQDO\VLV DQG  
FRQVLGHUDWLRQV 'LIIHUHQW SHRSOH ZLOO  
DEVWUDFW DQG HODERUDWH  
GLIIHUHQWVXEFRPSRQHQWVEDVHGRQWKHLUWUD  
LQJLQJQDQGFRIURW OHYHO  
\$ PDLQ FRQVLGHUDWLRQ LQ WHUPV RI  
DEVWUDFWLQJ DQG  
HODERUDWLRQLVWKDWHQJLQHHULQJZRUNLQJLQJ  
HVXE\VVWHPD\ KDYH OLPLWHG NQRZOHGJH RI  
RWKHU VXE\VVWHPV 7KHVH RWKHU VXE\VVWHPV  
DUH WKHQ SHUFHLYHG DV EODFN ER[HV ZLWK  
OLPLWHG NQRZOHGJH RI WKH LQWHUIDFHV  
EHWZHHQ VXE\VVWHPV 6R RQH UHVHDFK  
TXHVWLRQ LV KRZ RQH FRQGXFWV DEVWUDFWLQJ  
DQG





VXEJURXSZRROGEHUHTXLUHGWRH[FHHGWKUHVKR  
OGOYHO<sup>y</sup><sub>T</sub>  
7KLV PLJKW OHDG WR WKH FKRLFH RI GHVLJQV  
WKDW PLJKW EH OHVV  
SUHIHUUHGWRWKHRUJDQLJDWLRQ)LJ  
7RLOOXVWUDWHFRQVLGHUWZRGHVLJQVSDQG%  
VXSHULPSRVHG RQ FRQWRXUV RI FRQVWDQW  
YDOXH LQ D GHVLJQ VSDFH RI WZR  
DWWULEXWHVXDQGYZKHUHPRUHRIHDFKDWULE  
XWHLVSUHIHUUHGWR

\$Q D[LRPDWLF DSSURDFK FRXOG UHTXLUH WKH  
IROORZLQJ GHVLGHUDWXP

**Axiom:** *There will be no design that lies within the acceptable target region that is less preferred to one outside the target region.*

,I WKH RUJDQLJDWLRQ ZLVKHV WR IROORZ WKLV  
D[LRP WKHQ WKH  
UHTXLUHPHQWV FDQQRW EH VHW LQGHSHQGHQWO\  
IRU HDFK VXE  
FRPSRQHQW WKH UHTXLUHPHQW UHJLRQ PXVW EH  
ERXQGHHG E\ D FRQWRXU RI FRQVWDQW  
SUHIHUHQFH 7KLV OHDGV WR WKH IROORZLQJ  
7KRUHP

**Theorem:** *If axiom 1 is satisfied, then the requirement region must be defined by a contour of constant preference.*

7KLV LPSOLHV WKDW DQ RUJDQLJDWLRQ PXVW  
GHFODUH WUDGHRIV  
DPRQUHTXLUHPHQWVWLQVWHDGRIVHWLQJWKHP  
LQGHSHQGHQWO\IRU HDFK SK\VLFDQ  
VXEFRPSRQHQW 7KH \V\WHPV HQJLQHUU ZRXOG  
FRPPXQLFDWH WKH WUDGHRIV DQG KHOS VHOHFV  
WKH GHVLJQ WKDW  
ZRXOGEHPRVWSUHIHUUHGWRWKHRUJDQLJDWLRQ

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7KH ZRUNVKRS KHOSHG HVWDEOLVK UHVHDFK  
GLUHFWRQV IRU  
\V\WHPVHQJLQHULQJ\XFKDVWKHQHGHGIRUDVRX  
QGWHUPLQROR\ E\ ZKLFK PXOWGLVFLSOLQDU\  
WHDPV VKRXOG RSHUDWH WKH UHDFK]DWLRQ RI  
WKH SKHQRPQRQWRYDOXH FRQFHSW RI \V\WHPV  
WKH TXDQWLILFDWLRQ RI YDOXH DJJUHJDWLQJ  
JURXS SUHIHUHQFHV VKDULQJ UXOHV  
QHJRWDWLRQV H[FKDQJH RI SD\PHQWV  
LQFHQWLYH  
VWUXFWXUHVVDQGFURSRUDWHXWLOLW\IXQFWLRQ  
VZHUHDOOSRLQVWKDW  
ZHUHDLVHG2WKHUWRSFLVDOVRLQFOXGHGWKHF  
KDQJHRIUDPHDV  
ZHJRGRZQDQRUJDQLJDWLRQDQGRZWKUXVWPLJK  
WFRPHIURP EHZRZ DQG ZKHWKHU WKH  
RUJDQLJDWLRQDO KDV WKH FDSDELOLW\ WR  
DOORZIRUUDPHFKDQJHVDWKKHGLIHUHQWOHYH  
OV"2WKHUWRSFLVRI GLVFXVVLQJ DOVR LQFOXGHG  
KRZ WR GHILQH YDOXH PHDVXUHV IRU  
WUDGHRIVDQGLQGLIHUHQFHFXUYHVIRUDQRUJDQ

OHVV'HVLJQ%OLHVZLWKLQWKLWUHLRQDQGWKHU  
HIRUHPHHVWVKH  
WDUJHWUHTXLUHPHQWVWKDWKDYHEHHQVHWEX  
WLWKLVDORZHUHDOXH  
WKDQGHVLJQ\$ZKLFKLVRXWVLGHWKLWUHLRQEXW  
OLHVRQDKLJKHU  
YDOXHFRQWRXU7KXVWKHGHVLJQWKDWZRXOGEH  
LQGXFKGE\WKLV UHTXLUHPHQW UHJLRQ LV OHVV  
SUHIHUUHG WKDQ RQH WKDW ZRXOG EH  
UHMHFWHG E\ WKH UHTXLUHPHQW 7KLV  
GLIHUHQFH LQ FKRLFH

L]DWLRQDVZHOODV KRZ \V\WHPV HQJLQHUU  
UHFHLYHVKDUH LQIRUPDWLRQ IURP  
GLIHUHQWGLYLVLQVWRPDNHGFLVLQV

7KH ZRUNVKRS DOVR EUDLQVWRUPHG QXPHURXV  
RWKHU LVVXH  
LQFOXGLQJ+RZGR\RXFKDQJHDFXOWXUHRUGLUHFV  
LRQ"+RZGR

\RXNRZLIV\WHPVHQJLQHULQJZRUNV"+RZGRZH  
NQRZ WKDW WKLV LV QRW RQO\ DQHZDSSURDFK  
EXWD EHWWHU DSSURDFK"

:KDFDQZHFKDQJHLIZHKDGWKHIOH[LELOLW\WRV  
WDUWRYHU" :KDW FDQ ZHFKDQJH LIZHFDQQRW  
VWDUW RYHU":KDW DUH WKH FRJQLWLYH  
OLPLDWLRQV DQG LPSOLFDWLRQV RI  
DEWUDFWLRQ DQG HODERUDWLRQ" +RZ GR ZH

LGHQWL\ WKH FRPPRQ GHQRPLQDWRU  
NQRZOHGJHEDVHIRUDV\WHPVHQJLQHUU":KDWLV  
WKHFRVWRI

JLYLQJXSPRGXODULW\WUHDWLQJHDFK\XEFRPSRQ  
HQWDVDEODFN  
ER[LQGHSHQGHQWO\"+RZGR\XPDNHJRRGLQWHUID  
FHV",\WKH H[LVWLQJ VWUXFWXUH RI PRGXODULW\  
ORFNHG LQWR WKH VXQN FRVW

SULQFLSOH"+RZGRHVFRUSRUDWHVWUXFWXUHHDOO  
RZIRULQWHUIDFLQJ  
DQGFKDQJHRIUDPHVRPHFRPSDQLHVDUHULJLGV  
HVD\ZDLW

WLOOQH[WWLPHRUQH[WSURGXFWRWKHUVKDYHP  
RUHIOH[LELOLW\7KH  
UROHRIKHXLVWLFVDQGLQWXLWLRQYVWKHRU\  
QFKRULQJDQGHVLJQ IL]DWLRQ DQG

UHTXLUHPHQWV YV YDOXH ZHUH RWKHU LVVXH  
WKDW DURVH LQ WKH EUDLQVWRUPLQJ +RZ GR ZH  
DGGUHVV WKH FXUHQW HGXFDFWLRQ JDSV" ,6(  
GHSDUWPHQWV WHDFK 252SWLPL]DWLRQ

EHFDFXVHRISHUFWSLRQVDQGDQNLQJ  
9 & 21 & 86, 21

6\WHPVHQJLQHULQJSURYLGHVDPDQRSSRUWXQ  
LWLHVIRUYDOXH  
FUHDWLRQLQODUJHGHQWUSULVHV,WLVKHOSIXOW  
RWKLQNRIDV\WHPV

HQJLQHUUHVQRHFKRPNHVGHFLVLQVZLWKLQWK  
HFRQWH[WRID \V\WHP IRUPHG RI PXOWLSOH  
VXE\WHPV %HFDXVH RI WKH  
PXOWGLVFLSOLQDU\ QDWXUH RI WKLV HIIRUW

FDUH PXVW EH WDNHQ ZKHQ FRQVLGHULQJ WKH IUDPH WKDW D V\VVWHPV HQJLQHHU LQFRUSRUDWHVZKHQGHQDOLQJZLWKWKHGLIIHUHQ WVXEFRPSRQHQWV &RQVLGHUDWLRQV IRU WKH LQWHUIDFHV DW ERWK WKH SK\VLFDQ DQG VRFDOOHYHOVVKRXOGDOVREHFRQVLGHUHGLQD OOWKHUHLVURRP IRU UHVHDFK RQ D[LRPDWLF GHULYDWLRQV WKDW LQFRUSRUDWH EHKDYLRUDODVSHFWVDQGOHGDGWRGHVLUDEOHSU RSHUWLHVLUQV\VVWHPV HQJLQHHULQJ

3URIHVVRUSEEDVLVDXWKRUDQGFQDQWKRURIPXOWLSOH UHVHDFKSDSHUVDQGLV FRDXWKRURIPRXQGDWLRQVRI'HFLVLRQ\$QDO\VLV'ZLWK5RQD OG+RZDUG+HLVD PHPEHURI,1)2506DQGDVHQLRUPHEHURIWKH,(((

\$&.12:/\*0(17

7KLV ZRUN ZDV VXSSRUWHG E\ WKH 1DWLRQDO 6FLHQFH )RXQGDWLRQ DZDUGV &00, DQG &00, 7KH YLHZV LQ WKLV ZRUN DUH WKRWH RI WKH DXWKRU DQG GR QRW QHFHVVDULO\ UHSUHVHQW WKH YLHZV RI WKH 1DWLRQDO 6FLHQFH )RXQGDWLRQRUWKH)HGHUDO\*RYHUQPHQW

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/6XPPHUVZKDW\RX5HDOO\QHHGWRNQRZ1HZ<RUN7LPHV - DQWK 5 \$ +RZDUG DQG \$ (SEEDV )RXQGDWLRQV RI 'HFLVLRQ \$QDO\VLV3HDUVRQ1< YRQ 1HXPDDQ - 2 0RUJHQVWHUQ 7KHUR\ RI \*DPHV DQG (FRQRPLF%HKDYLRUQGHG3ULQFHWWRQ8QLYHUVLW\3ULQFHW RQ1- / 6DYDJH 7KH 7KHUR\ RI 6WDWLWVWLFDO 'HFLVLRQ -RXUQDO RI WKH \$PHULFDQ6WDWLWVWLFDO\$VVRFLDWLRQSS \$ (SEEDV )RXQGDWLRQV RI 0XOWLDWWULEXWH 8WLWLW\ &DPEULGJH 8QLYHUVLW\3UHVV,Q3UHVV -(0DWKHVRQDQDQ\$+RZDUG\$QLQWURGXFWLRQWRGHFLVLRQ DQDO\VLV,Q 5 \$ +RZDUG - (0DWKHVRQ HGV 7KH 3ULQFLSOHV DQG \$\$\$OLFWRQVRI'HFLVLRQ\$QDO\VLV 9RO,6WUDWHJLF 'HFLVLRQV\*URXS 0HQOR 3DUN &\$ 5HSULQWHG IURP 0DWKHVRQ - ( DQG 5 \$ +RZDUG\$UHSRUWE\WKH(XURSHDQ/RQJ5DQJH3ODQQLQJ6HUYL FH 6WDQIRUG5HVHDFK,QVWLWXWH5HSRUW \* \$ +DJHOUJJ )XQGDPHQWDOV RI 'HFLVLRQ 0DNLQJ IRU (QJLQHHULQJ 'HVLQ DQG 6\VVWHPV (QJLQHHULQJ 6HOISXEOLVKHG \$UOLQJWRQ9\$ 5 / .HHQH\ \*URXS SUHIIHUHQFH D[LRPDWLF]DWLRQ ZLWK FDUGLQDO XWLWLW\0DQDJPHQW6FLHQFH 5/.HHQH\RXQGDWLRQVIRUJURXSSGHFLVLRQDQDO\VLV'HFLVLR Q \$QDO\VLV \$QDO\VLV± &KDLQ0RQWH&DUORSSURDFK3UHFLVLRQ(QJLQHHULQJ

**SOL(SEEDVLV3URIHVVRURIPRXQGDWLRQVRI'HFLVLRQ\$QDO\VLV'ZLWK5RQD OG+RZDUG+HLVD PHPEHURI,1)2506DQGDVHQLRUPHEHURIWKH,(((**  
 HULQJDQDQ\$+RZDUG\$QLQWURGXFWLRQWRGHFLVLRQ DQDO\VLV,Q 5 \$ +RZDUG - (0DWKHVRQ HGV 7KH 3ULQFLSOHV DQG \$\$\$OLFWRQVRI'HFLVLRQ\$QDO\VLV 9RO,6WUDWHJLF 'HFLVLRQV\*URXS 0HQOR 3DUN &\$ 5HSULQWHG IURP 0DWKHVRQ - ( DQG 5 \$ +RZDUG\$UHSRUWE\WKH(XURSHDQ/RQJ5DQJH3ODQQLQJ6HUYL FH 6WDQIRUG5HVHDFK,QVWLWXWH5HSRUW \* \$ +DJHOUJJ )XQGDPHQWDOV RI 'HFLVLRQ 0DNLQJ IRU (QJLQHHULQJ 'HVLQ DQG 6\VVWHPV (QJLQHHULQJ 6HOISXEOLVKHG \$UOLQJWRQ9\$ 5 / .HHQH\ \*URXS SUHIIHUHQFH D[LRPDWLF]DWLRQ ZLWK FDUGLQDO XWLWLW\0DQDJPHQW6FLHQFH 5/.HHQH\RXQGDWLRQVIRUJURXSSGHFLVLRQDQDO\VLV'HFLVLR Q \$QDO\VLV \$QDO\VLV± &KDLQ0RQWH&DUORSSURDFK3UHFLVLRQ(QJLQHHULQJ