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A critical assessment of research findings and test methods**

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The influence of plants on productivity

A critical assessment of research findings and test methods

Iris Bakker & Theo van der Voordt

Abstract

Purpose This paper aims to review available research into the impact of plants on people and labour productivity in order to test a number of hypotheses and the reliability and validity of “evidence based” statements.

Methodology An extended literature review has been conducted of research concerning the potential impacts of plants on people and labour productivity. In order to be able to compare the findings of different researchers, an analysis has been made of similarities and dissimilarities with regard to the research context, starting-points and test methods.

Findings The paper identifies a lack of precise descriptions of the research design and poor comparability between different research with regard to the characteristics of the plant, test persons, test procedures, surrounding conditions and contents of the reports. Although we may conclude that plants can have a positive impact on the productivity of human beings, it is remarkable that in research reports and research papers the properties of the plant itself are only mentioned by exception. The condition of the plant - whether it is healthy or not – is not described at all.

Limitations “Only” 17 studies and underlying papers were investigated and no new research has been conducted with the proposed improvements.

Practical implications The findings can be used by managers to legitimate investments in plants and by researchers to improve (the comparability of) research into plants.

Originality. In addition to the review of the impact of plants on different types of productivity a vision is presented about the impact of the vitality of plants. Furthermore recommendations are given on how to cope with the methodological problem of poor comparability of research.

Keywords plants; vitality; productivity; research methods; comparability; model;

Introduction

In order to be able to design the optimal working environment where people can flourish in their work and organisations will be successful, it is important to know how the physical environment affects people and productivity. One of the variables is the presence of plants. In search for evidence based knowledge about the impact of plants on labour productivity it turned out that the existing literature is not always clear on what the impact exactly is. It is needed to define this impact more exactly. Second, we observed a large variety of research methods and test conditions. As a consequence, the comparability of different research projects and the conclusions that came out of the research is limited. And third, the first scan of a number of studies and included references showed that in particular information about the plants themselves is often lacking. This is an omission, because probably nobody will be more productive by seeing a faded or dead plant. Apart from the appearance, the type of the plant may be an important issue too. It may be expected that people respond differently when seeing a cactus or a rose plant. These observations have lead to three main questions for a more extensive literature review on the impact of plants on productivity:

1. What is the influence of plants on productivity?
2. Are different studies sufficiently comparable to draw sound conclusions?
3. What is the impact of the appearance and vitality of the plant?

These questions have been rephrased into three hypotheses:

Hypothesis 1: Plants have a different impact on different types of productivity.

Productivity covers a diversity of activities such as routine work and creativity. Creativity tasks and complex knowledge work need inspiration and deepening. Through history many statements of famous philosophers, writers and artists such as Nietzsche or Liszt refer to the inspiring and deepening effect of nature. Our hypothesis is that in case of routine work plants might help to support well-being and as such keep people going on, whereas in case of creativity work a positive effect is expected in relation to inspiration and deepening.

Hypothesis 2: Research concerning the impact of plants on productivity is not well comparable.

Research is rather complex. Even when the focus is just on one “dependant” variable, plants, many “independent” variables can influence the results. It is expected that research so far does not use standardised research methods.

Hypothesis 3: Both the appearance, type and vitality of the plant have an impact on the productivity.

One of the wonders of nature is its infinite variation combined within certain patterns and structures. Each variety has its own characteristics. As a consequence one might expect different effects of different plants. In particular the vitality of a plant is expected to be important. Probably a healthy plant has a more positive impact on people than a plant that is not vital. In addition it is important that a plant lives in an environment with healthy conditions that support the plant and conditions people need.

Research methods and conceptual model

Initially, 17 studies from renowned researchers and research institutes were collected (Appendix A). These documents have been scanned on possible effects of plants on people and labour productivity, relevant variables and references for further reading (see list of references). Without any exception all studies make a significant contribution to the field. Together an incredible amount of data has been collected on many different effects. Second, in order to enlarge the knowledge that came out of the documents - both technical and psychological – discussions with specialists of the knowledge institutes TNO and Fyttagoras/TNO have taken place as well. Third, because of the many different phenomenon's that are being mentioned in the studies and additional references, the need came up to develop a conceptual model that visualizes the different types of impact of plants on human beings (Figure 1). Two different mechanisms were traced:

1. *Evolutionary influence.* Since our genesis we are surrounded by green plants and trees. From this point of view it is generally assumed that seeing plants has in general a restful effect (Ulrich, 1984; Kaplan & Kaplan, 1989).

2. *Healthy indoor climate.* Plants have an impact on the indoor climate; this indoor climate in turn affects people and their productivity (Wolverton, 1989; Wood et al, 2004).

The evolution of human beings and a healthy indoor climate affect people in three ways: plants evoke a physical/physiological response, an affective response and/or a cognitive response. In the literature six components of the indoor climate are being mentioned in relation to the impact of plants: light, temperature, relative air humidity, air quality, sound and static electricity. Another point of attention is the characteristics of plants itself, including form properties and metabolics. The latter are hardly mentioned in the literature.

This conceptual model has been used as a guiding principle to analyse and discuss the collected data to examine the research findings and conclusions in the studies more closely. In a cyclic process of reading, reflecting, discussing, further reading etc. a list of items has been traced with regard to the test conditions (Table 1). This list includes six main aspects: 1) characteristics of the plant; 2) the test surroundings; 3) the test persons; 4) the test process; 5) test strategies; and 6) methods and variables. Table 2 shows the variables that have been investigated in each research.

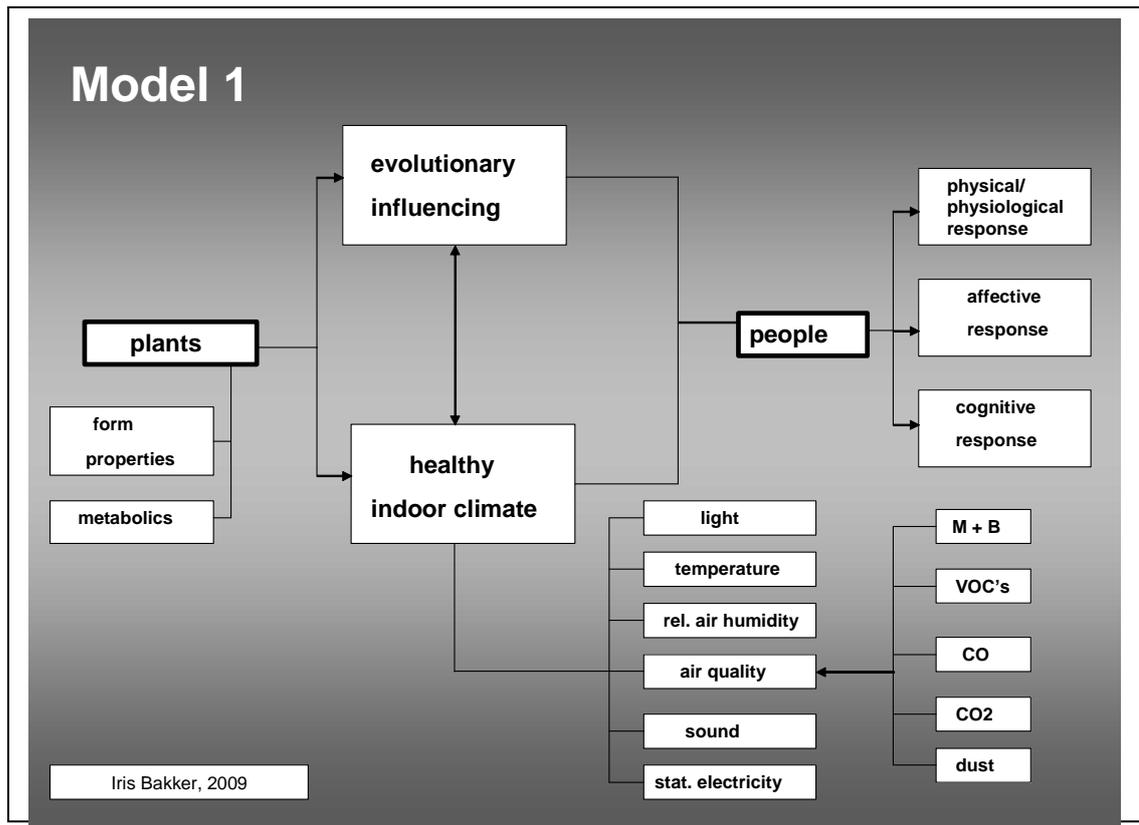


Figure 1: Conceptual model of the impact of plants on people (M+B = Molds and Bacteria; VOC's = Volatile Organic Compounds)

Research findings

a. Effects of plants on human beings: physical/ physiological, affective and cognitive response

The next responses are mentioned rather often:

- *physical/physiological*: primary physical responses are effects on blood pressure and heart beat and physiological decrease of complaints of headache; secondary responses are physiological phenomena like faster recovery (all documents excl. no 9, 6, 10, 13, 14)
- *affective*: positive affective response on mood and affective behaviour like self-confidence, alertness or less aggression and positive feelings like pleasure (all documents, excl. no 9, 13, 14, 16 & 17)
- *cognitive*: positive cognitive responses are better concentration capacity and higher response speed (all documents excl. no. 9, 13 & 14). Ulrich (1984), Fjeld (1998) and Lohr et al (1996) showed significant statistical correlations between seeing plants and physical/physiological, affective and cognitive responses. These researchers use different methods like questionnaires, the Zipertest (Zuckerman Inventory or Personal Reactions), interviews and observation of behaviour. Unfortunately a clear explanation of the set-up of these methods is often missing.

Table 1: Overview of items to compare different research on plants

Plants	Test surroundings	Testsubjects	Testproces	Test	Methods and Variables
spot <i>position in space</i> <i>height of view</i> <i>indoor/outdoor</i> <i>view</i>	institute <i>outdoor area</i> <i>laboratory</i> <i>education</i> <i>office</i> <i>shop</i> <i>hospital/care</i>	testsubjects <i>men</i> <i>women</i> <i>children</i> <i>patients</i> <i>students</i> <i>employees</i> <i>age</i> <i>number</i> <i>sort of work</i> <i>concentration</i> <i>creativity</i> <i>routine</i>	reduction hawthorne-effect <i>attention</i> habitation proces <i>attention</i> test surrounding <i>clear information at the beginning</i> <i>intensive accompaniment</i> <i>acceptation management</i> test aspects <i>placebo</i>	observation <i>observation by testsubject</i> <i>observation researcher</i> <i>technical supporting measurements</i> <i>data semantic questionnaire</i> <i>data standard interview</i> <i>data interview/ survey</i> <i>data question conversation</i> <i>questionnaire</i> <i>computer program</i> biofysical observation <i>interview method</i> <i>heartbeat</i> <i>guidance question conversation</i> <i>syst bloodpressure</i> <i>no guidance</i> <i>muscle tension</i> <i>computer program</i> <i>skin conductance</i> <i>ZIPER test</i> <i>electr brain activity</i> number measurements <i>fee</i> <i>credit</i>	information <i>observation</i> <i>by testsubject</i> <i>by researcher</i> <i>biofysical</i> questionnaires <i>standard</i> <i>scoremodel</i> <i>quantative</i> <i>qualitative</i> <i>interview method</i> <i>guidance question conversation</i> <i>no guidance</i> <i>computer program</i> <i>ZIPER test</i> <i>fee</i> <i>credit</i> task <i>association task</i> <i>key typing task VDT</i> <i>computertask</i> <i>sortingtask</i> <i>concentration task</i> technology <i>air/ ventilationsystems</i> <i>lightsystems</i> <i>measurement airquality</i> concept <i>position plants</i> <i>number plants</i>
sort	space type <i>one person space</i> <i>two persons space</i> <i>multi persons space</i> <i>various</i>	commitment testpersons <i>relevance</i> <i>seriousness of participation</i> <i>to participate own choice</i> <i>involvement final result</i> <i>preference for plants</i>		biophysical observation <i>interview method</i> <i>heartbeat</i> <i>guidance question conversation</i> <i>syst bloodpressure</i> <i>no guidance</i> <i>muscle tension</i> <i>computer program</i> <i>skin conductance</i> <i>ZIPER test</i> <i>electr brain activity</i> number measurements <i>fee</i> <i>credit</i>	
variety					
intensity					
dimension/number per square m					
number					
size	space characteristics <i>number of windows</i> <i>size of windows</i> <i>size of space</i>				
cleanliness order	relation to temperature				
maintenance situation	light level				
pot ground/hydroponics	relation lighting <i>fluorescent broad spectrum</i> <i>neon light</i>				
pot size	day light				
form pot	Relative Air Humidity				
artificial plant	ventilation system <i>natural ventilation</i> <i>mechanical ventilation</i> <i>air treatment</i> <i>airco</i>				
image plants	quantity ventilation <i>design ventilation quantity</i> <i>real ventilation quantity</i>				
flower	sound				
micro-organism	static electricity				
	colour space				
	fragrance				
	interior elements				
	smoke				
	specification and VOC's				
	parts and value parts of dust				
	CO2 and value CO2				
	CO and value CO				
	moulds				
	pathological micro-org.				
	time <i>link to seasons</i> <i>link day/night</i>				
	one cell organism				
	wether				
				effects <i>affective feeling</i> <i>affective mood</i> <i>affective behaviour</i> <i>physical primary</i> <i>physical secondary</i> <i>phygological effects</i> <i>cognitive</i> <i>cognitive concentration</i> <i>cognitive memory</i> <i>cognitive reaction time</i> <i>cognitief fouten</i> <i>cognitive discipline</i> <i>adiposis</i> other mentioned effects <i>productivity/performance</i> <i>sound</i> <i>ecologically/reduction energy</i> <i>staff keeping and recruitment</i> <i>on working environment</i> <i>on plants</i> start conditions <i>single plant</i> <i>many plants</i>	

In most research also quantitative effects were mentioned, be it quite underexposed. The following quantitative data are interesting:

- Wolf (2002) mentions in her research at shops an increase of sale concerning all products of 12% when plants are present;
- Lohr et all (1996) appoints an increase of the response speed of 12% at simple recognition tests;
- Fjeld (1995) shows a decrease of seasons symptomatic physical complaints of 23% at 51 office employees;
- Research of Fjeld (1998) among 48 employees of an X-ray division showed a 25% decrease of health complaints by using plants
- In 2001-2002 Fjeld revealed an average 24 % reduction of physical complaints among different groups of 48 bank employees after the introduction of plants and light with a broad spectrum.

Table 2: Aspects that were mentioned in 17 studies

		Studies (numbers according to Appendix A)																	
Component	aspect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
Plants																			
spot	position in space	X	X	X		X		X							X	X		X	8
	height of view		X	X		X		X											4
	indoor/outdoor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	17
	view		X	X								X							3
sort			X	X		X	X	X			X		X	X	X		X	X	11
variety				X		X	X	X			X			X	X		X	X	9
intensity	dimension/number per square m			X		X	X	X			X			X	X				6
number			X	X		X	X	X					X	X	X	X		X	10
size				X		X		X				X	X					X	6
cleanliness order		X											X				X		3
maintenance situation				X		X										X		X	4
pot ground/hydroponics		X				X									X		X		4
pot size													X					X	2
form pot				X		X							X		X				4
artificial plant		X			X														2
image plants		X											X						2
flower					X								X						2
micro-organism						X													1
Test surroundings																			
type of environment	outdoor area	X						X					X			X			4
	laboratory							X						X	X				3
	education		X																1
	office		X			X	X											X	4
	shop															X			1
	hospital/care	X	X										X						3
space type	one person space		X			X	X											X	4
	two persons space																		0
	multi persons space							X											1
	various																		0
space characteristics	number of windows		X				X	X			X	X							5
	size of windows		X																1
	size of space		X			X	X	X			X			X	X			X	8
temperature	known					X	X	X		X				X				X	5
light level	known		X			X		X											3
type of light	fluorescent broad spectrum		X					X						X					1
	neon light		X					X						X					3
	unknown		X														X		2
day light	known	X	X	X				X								X			5
Relative Air Humidity	known		X	X		X		X		X				X				X	7
ventilation system	natural ventilation					X												X	2
	mechanical ventilation		X			X								X					2
	air treatment					X													1
	airco			X														X	2
quantity of ventilation	designed ventilation quantity													X	X			X	3
	real ventilation quantity					X													1
sound	known			X		X							X						3
static electricity						X													1
colour space	known						X	X											2
fragrance	known			X									X						2
interior elements							X	X			X	X							4
smoke				X		X							X	X					4
specification VOC's						X							X	X			X	X	5
value VOC's						X							X				X	X	4
parts of dust			X			X								X					3
value parts of dust						X													1
CO2						X								X				X	3
value CO2						X								X				X	3
CO			X			X												X	3
value CO						X												X	2
moulds			X			X													2
path micro-org.				X		X													2
time	which season(s)									X									1
	day/night																		0
one cell organism						X													1

Third, metabolics may have an influence on people. Plants form metabolics, chemical compounds with amongst other things fragrances and colour properties. These substances may be expected to influence people, but this has not been proven by research so far. Little attention has been paid to the impact of intermediary variables such as research conditions and test persons. So although the positive effects of plants on human beings are widely accepted and supported by research, we have to interpret the research findings carefully.

b. Effects of plants on the indoor climate

Plants and indoor climate affect each other. To be able to interpret research findings on the impact of plants correctly, detailed information is needed about the indoor climate in the test situation. But due to differences in descriptions and lack of essential information concerning technical data that might affect the process and the impact of plants it is rather difficult to draw clear conclusions. Nevertheless some interesting results have been found with regard to the six components of indoor climate that are included in the conceptual model: light, temperature, relative air humidity, air quality, sound and static electricity.

Light

With regard to photosynthesis the blue and red part of the spectrum are necessary for healthy plants. In many buildings light with a broad spectrum is absent, so probably insufficient blue and red light will be available for the plant. This obstructs the growth and also the processes of photosynthesis and metabolism. It is striking that in the examined studies both light colours (spectrum) and light intensity are usually not mentioned at all, in spite of its importance for the health of the plant. Vice versa the reflection of light on the leafs of the plants affects the variation on light colours in the physical surrounding.

Temperature

Stec et al (2005) revealed that an outside awning of plants is more effective than a regular awning. Schempp (2002) mentions a difference of 2 up to 3 degrees with regard to outside temperature by application of an outside awning with plants in combination with plants inside.

Relative air humidity

Research of Costa (1995) and Strickler (1994) showed that the relative air humidity of a space without air treatment increases with approximately 5% when plants are used. It is necessary to use a quite large number of plants. Lohr (1996) mentions an increase from zero to 15% if space is not ventilated; in a ventilated room there is an increase of 3 to 5 %. Applying plants means that you have to take care for them. When for instance the value of relative air humidity is too low, the stomata at the base of leafs will close.

Air quality

In the air volatile organic compounds (VOC's) occur, such as small dust particles, moulds, bacteria, metabolics, CO and CO₂. Air quality is expressed by the VOC's concentration which is quantified in ppm-value (parts per million). Based on the experiments of Wolverton (1989) it is known that a synergetic process between plant and micro organisms that attaches themselves to the rootstructure of the plant contributes to the reduction of the VOC's-value. Van der Wal (1993) proves that unrealistic amounts of plants are needed to reach a sufficient reduction of the VOC's value. Quite often the indoor climate in buildings is not optimal for plants and therefore also not optimal for the process of VOC's reduction. Plants also have a positive influence on the reduction of dust accumulation. Research of Lohr et al (1996) showed that plants in optimal conditions can cause a dust reduction of 20%. Plants are selected in buildings in such a way that they will not grow too rapidly, because rapid growth increases the exploitation costs too much. It may be concluded that a positive effect of plants is not the right argument to use of plants as a means to control or improve the indoor air quality. Ventilation is much more effective.

Sound

Research of Costa and James (1995) shows that the reverberation time of sounds with a high frequency is shortened when plants are used, and as such the space will be more quiet. At low frequencies more inflection of the sound takes place. Dependent of the exact location and the spreading, sound absorption takes place.

Static electricity

Employees working at least four hours at screens, undergo less inconvenience of static electricity, when plants are in their workspace, then other employees without plants in their rooms (Dortmont et al, 2001).

Overall we may conclude that in real working environments the influence of plants on the indoor climate is rather small. So this can not be a convincing argument to apply plants in working environment.

c The effects of plants on productivity

According to the studies that have been analysed, the question if plants have an impact on the functioning and productivity of people can be answered in a positive way (Table 3). Most studies mention the positive qualities of plants. However, it is hardly possible to compare the studies in a systematic way because of the lack of clear definitions of productivity and performance and a lack of clear information about which activities were measured, what exactly has been measured, what the characteristics were of the test persons and in which way the measured results were achieved. Because of the large amount of variables it is impossible to establish clear conclusions.

In spite of the methodological shortcomings we can discern a common red thread:

- Plants bring people in a better mood and improve confidence and openness of the mind to the surrounding world. Plants have also a positive social effect in relation to alliance and morality.
- If people are in a better mood, the perceived productivity increases, whereas the measured ('real') productivity score decreased.
- The amount of plants plays a role.
- The presence of a plant stimulates people in different ways.
- The effect of plants can be different depending from the activities.
- With regard to productivity of creative work, a clear positive relation is evident on the basis of the research above.

Table 3: Effects of plants on labour productivity (on alphabetical order of the author)

Research	Conclusions	Document number (appendix A)
Asami et al (1989)	indoor plants reduce the fatigue of the eye when working with screens	10
Conkin (1974-1978); Hirt et al (1997); Isen (1990-1993);	plants in offices lead to higher employee morale and higher effectiveness	7, 11
Knez (1995); Isen (1990, 1993);	if people are in a positive mood, their creativity raises	6, 11
Isen & Shalcker (1982)	positive phenomena stimulate the brain for recalling more information and they initiate more cognitive manipulation that causes a higher level of creativity	6
Larsen(1998)	a larger number of plants improves the mood, but reduces concentration; the perceived productivity increases in connection to the number of plants	1, 6
Lohr (1996)	plants lead to 12% increase of the response speed and reduce the number of mistakes	5, 8
Mayer (2006)	plants strengthen the capacity to think about life problems	1
Mayer & Frantz (2004)	plants evoke a positive feeling of alliance and increase problem solving capacity	1
Marchant & Srivens (1980/82)	With plants increase of productivity 10 - 15%	7
Ottoson & Grahn (2005)	staying one hour in a green space improves concentration	1
Shibata & Suzuki (2002)	plants have a larger impact on performance than on women; in spaces with a plant men perform better; conducting a sorting and association task men performed on a lower level than women in case of no plants in the room, but when a plant was placed in front of them, men performed better than women. The impact of plants was larger at the association task, then at the sorting task. Plants had a negative effect on women in sorting tasks.	1, 5, 11
Shibata & Suzuki (2002)	the presence of plants increases the performance score of women; in general the presence of a plant increases the mood and the appreciation of the space	11
Shoemaker (1992)	plants have no impact on work satisfaction	5
Stone (1998)	Plants have a negative impact on performance and task perception	11

Reflections on the attention paid to five test items

As has been said before, to improve the comparability of research on plants, a test structure has been developed with five test characteristics that should be described very clearly the plant; the test surroundings; the test persons; the test process; and the test itself. Furthermore standard items have been formulated per aspect. The collected studies have been examined on the attention paid to these five aspects and the components (Table 2).

a. The plant itself

Looking at the plant itself, most reports and papers only pay attention to its type, variety and number and sometimes the spot. Heights and sizes of pots are mentioned as well. The characteristics of the plant itself are usually not described at all. Several types of plants are used, with different varieties (Table 4). Particularly the *Dracaena* with the *Spathiphyllum* and the *Epipremnum* are often used. Because of the different plants that are involved in the investigations, the conclusions from the studies are not comparable.

Table 4: Names of plants appointed in the research documents (numbers refer to the numbers of the documents in Appendix A)

Plant species	Lohr (7)	Strickler (in 5)	Burchett Tarran (in 5)	Klein Hesselink (5)	Wood (16)	Wolverton (3)	Larsen e.a. (6)	Shabita& Suzuki (10 + 11)	van der Wal (13 + 14)
Aglaonema	X								X
Chamaedora	X								
Dracaena	X	X	X		X		X	X	
Epipremium	X		X		X				X
Homalomena	X								
Hoya	X								
Philodendron	X	X						X	
Sansevieria	X								
Scindapsus	X								
Syngonium	X								
Dizygotheca		X							
Ficus benjamina		X		X					X
Hedera		X							
Howea			X		X				
Spathiphyllum			X	X	X				X
Schefflera			X		X				
orchidee						X			
bromelia achtigen						X			
Augusta									
Phycorapis								X	
Strelizia								X	

b. Test surrounding

Most studies mentioned whether the tests have taken place inside or outside. In all studies, the environment of the test is described, including offices, a laboratory, shops, care sector and education buildings. Most attention is paid to the size of the space and the relative air humidity. All other aspects of the test surroundings are mentioned only very briefly and to an insufficient degree. Colour specification is extremely limited, whereas this variable affects the light frequencies required for the photosynthesis of the plant.

c. Test persons

The test persons vary from children to students (graduates and undergraduates), clients and employees and include men and women in different sectors. Usually reports and papers don't give any information about the psychological and social psychological situation of test persons or personal characteristics (beside age and sex), personal conditions or mood specifications. So, no valid statements can be made about the impact of these issues. Sometimes attention is given to the willingness of people to participate in the experiment.

d. Test process

Processes are very complex; there are many factors playing a role and also influencing each other. No single study paid attention to psychological effects like the Hawthorne effect. In a number of cases attention was paid to habituation. However, the way that habituation has been defined and being measured is described insufficiently. It is possible that both the habituation of the test persons and the early effects of VOC'S-reduction of plants have affected the test results, but in which way is still not known.

e. Test methods and variables

Observations, measurements, impact and test duration are only comparable in a limited way. The observations vary from individual perceptions of the test persons to observations by research workers and standard questionnaires with scores and/or scales. Biophysical observation has taken place to a limited extent.

It may be concluded that because of the huge variety in test characteristics the comparability of the 17 analysed documents is limited. Testing phenomena like effects of plants on productivity is related to many variables, so it is a very complex process. As a consequence it is nearly impossible to draw sound and transparent conclusions. Many studies do not pay sufficient attention to important terms. Quite often terms have not been formulated consistently or accurately. At this moment, there is no standard research framework that can be used as a guideline to design research. A positive exception is study nr. 5 of TNO (Klein Hesselink, 2006). The appointment of 55 aspects is a relatively complete description. The analysis of Fjeld (2002) scores also high with an appointment of 44 aspects. The more technical considerations of Wood (2004) and Van de Wal (1991) have high scores as well. They focus on a pure technical and well-defined input.

A closer look at the appearance and vitality of a plant

Table 5 shows an overview of relevant aspects with regard to appearance and vitality. Based on this scheme, all remarks about the appearance and vitality of plants have been collected and analysed. It is obvious that researchers don't pay sufficient attention to the appearance of plants or their health condition. Research with significant evidence of the impact of the appearance and health condition of a plant on human behaviour has not been found yet. Nakamura and Fujii (1990, 1992) just mention that plants with flowers give most entertainment. Lohr and Pearson-Mims (1996) and Costa (1995) discuss the size of the leaf and/or the length of the little hairs in connection with admission of specks of dust and chemical substances. Only the study of Van Dortmont and Bergs (1997) discusses plant properties based on conversations with garden experts.

Table 5: Characteristics of plants and its application in 17 studies

Plant characteristics			17 studies (numbers refer to Appendix A)																	
nr	aspect	subaspect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	chemical activity	bioproces system																		
2		admission chem. compounds																		
3		quantity of transpiration									X									1
4	plants differentiation	plant type			X	X	X	X	X						X	X				5
5		plant sort	X			X	X	X	X			X		X				X	X	8
6		plant variety				X	X	X	X			X						X		5
7	sizes	plant height			X	X	X	X			X	X							X	6
8		planten width			X															1
9		proportions			X															1
10	form	appel/pear form																		
11		fullness/ mass																		
12		horizontally or straight																		
13	structure	structure plant			X															1
14		structure branches																		
15		structure leaf																		
16		mesophyll																		
17	leaf	number/ intensity				X		X				X			X	X			X	6
18		size			X												X		X	3
19		form																		
20		surface/ tactility characteristic					X													1
21		colour mix			X															1
22		colour expression			X															1
23		structure			X															1
24		position																		
25		expression																		
26		brilliance																		
27		difference colour front/back																		
28		leaf edge																		
29	fragrance plant	nature			X	X														2
30	flower	mentioned				X								X						2
31		expression																		
32		form																		
33		structure																		
34		colour																		
35		colour differentiation																		
36		position																		
37		fragrance																		
38		number/ intensity																		
39		brilliance																		
40	seeds and fructification	number																		
41		size																		
42		form																		
43		colour differentiation																		
44		colour expression																		
45		structure																		
46		position																		
47	dynamics	dynamics																		
48	external factors	pot form			X		X							X					X	5
49		pot ground/hydroponics	X				X									X		X		4
50		position		X					X											2
51		integration environment																		
52		care and carefulness	X				X							X			X		X	5
53		solitarily/group																		
54	performance	fine or grove structure																		
55	metabolics																			
56	health	degree of vitality				X														1
	TOTAL		2	2	11	4	8	3	5	0	0	4	1	4	2	3	2	3	6	60

The comparative analysis shows that hardly any attention is being paid to the properties of the plant itself, like the shape of the leafs, colours and structures of the vascular bundle. One can imagine that a cactus has another effect on people than a rose plant, and that an unhealthy or nearly dead plant makes people feel less pleasantly than a strong and healthy plant. These considerations are missing in nowadays research.

Discussion and conclusions

Hypothesis 1: Plants have a different impact on different types of productivity.

Although a consistent positive influence of plants on creativity came out from the studies mentioned, the influence of plants on overall productivity varies. In general plants have a positive impact on the physical/physiological and affective response of people. Through centuries people are aware of the impressive nature. Modern research supports the so-called “Biophilia Hypothesis” that refers to the biological basis for human values in nature (Kellert, 1993). There is also a growing awareness of the importance of nature to children’s development – intellectually, emotionally, socially, spiritually, and physically (Kellert, 2005; Moore and Cooper Marcus, 2008). Plants support people in their feelings of safety, because all plants have a clear structure. Concerning cognition, the effects of plants are

different for various reasons. Many factors are playing a role. Another issue is the infinite diversity of people, their way of being, living, doing, feeling and thinking. All people are completely different concerning Intelligence and Emotional, Spiritual and Physical Quotient. Their personal situations are also different. So one might question if it is really possible to measure the effects of plants on people.

Hypothesis 2: Research concerning the impact of plants on productivity is not well comparable.

Due to the lack of essential information and to indistinct and incomplete data, the comparability of the analysed studies is limited. Accuracy concerning the various aspects playing a role in research is necessary to establish clear conclusions. Because of the complexity of this type of research and the lack of accurate information about the many aspects playing a role there is doubt about the validity of the posited conclusions from present research.

Hypothesis 3: Both the appearance, type and vitality of the plant have an impact on the productivity.

None of the analysed studies discussed the appearance of the plant on a scientific basis.

Only study 3 refers to the vitality of the plant, whereas, hypothetically it is assumed that the more healthy the plant, the more positive the impact on people. It is remarkable that researchers were looking for a physical environment that is healthy for human beings, without paying sincere attention to the plant itself. Plants are – like ourselves - living beings and are changing permanently their form, colours and fragrances. It is really important to treat plants with respect. Nowadays, they are cultivated in a world with emphasis on low costs and less time. So, it's really the question if the cheap pots and cheap potting soils are the benefit of the plants it selves. Moreover, the spots where plants in buildings will be placed are often too windy, too dark without day light, or lack the blue and red light of the spectrum. When plants are unhappy, they can't make people feel happy. When more attention will be paid to the plant itself and when the plant will stay more healthy, this stronger interaction between people and plant will generate positive effects in a more socialising way. An interesting example is a home for older people, where the older men and women were allowed tot take care for their own plants, which they had selected themselves. These elderly people were feeling better and had fewer complaints (Langer & Rodin, 1976, 1977). Just by bringing user involvement in the organisation, both plants and users of a building will be happier.

Recommendations

It is severely recommended to make the approach of future research less unambiguous in order to improve its comparability with other research and to support sound conclusions. For that purpose a more elaborated standard research approach is needed. The tables and schemes that came out of this paper may be helpful here, in particular in recording of the properties of plants in a structured way. It is also important to use unambiguous definitions without overlaps and to pay more attention to the appearance and vitality of plants. This will help to create a more complete picture. However, people have to be humiliate. Nature is so infinite in her expressions, that it is impossible to gather all variations of nature in a model made by human beings. Finally it is recommended to pay more attention to the health of the plants themselves. It is hypothesized that the happier the plant, the more positive effect the plant has on human beings. It is interesting to study this hypothesis more closely.

References

(in addition to the list of 17 studies mentioned in Appendix A and if applicable with a link to the number of the study in Appendix A that used this reference)

Asami D.K. et al, (1995), Effects of ornamental foliage plants on visual fatigue caused by visual display terminal operation. *Journal of Shita* 7, 138-143 (doc 10).

Conkin (1974), Interior plantings bring nature indoors. *Amer Nurseryman* 139 (2): 12-13, 105-112 (doc 7).

Cokin (1978), Interior landscaping. *J Aboriculture* 4: 73-79 (doc 7, 11).

- Costa, P. and James, R.W. (1995), Constructive use of plants in office buildings. *Lecture notes for the catalogue of the symposium Plants for People* (doc 3, 5, 8).
- Csikszentmihalyi M. (1998), *Creativiteit*, Amsterdam: Boom.
- Csikszentmihalyi, M. (1996), *Creativity : Flow and the Psychology of Discovery and Invention*. New York: Harper Perennial.
- Fjeld, T. (1995), The effects of interior plants for offices, *Report Symposium Plants for People* (doc 3).
- Isen A.M., and T.E. Shaker (1982), The effect of feeling state on evaluation of positive, neutral and negative stimuli, *Social Psychology Quarterly* 45(1), 58-63 (doc 6).
- Isen A.M. (1990), The influence of positive and negative affect on cognitive organisation: Some implications for development. In N. Stein, B. Leventhal & T. Trabasso (Eds), *Psychological and biological approaches to emotion* (pp 75-94). Hillsdale N.J.: Lawrence Erlbaum, (doc 6).
- Isen, A.M. (1993), Positive affect on decision making. In M. Lewis & J.M. Haviland, (Eds.), *Handbook of emotions*, pp 261-277) New York: Guilford (doc 6)
- Kaplan R. & S. Kaplan (1989), *The experience of nature: A psychological perspective*. New York: Cambridge University Press (doc 1, 2, 6, 10, 11).
- Kellert, S.R. (2005), Nature and Childhood Development. In: *Building for Life: Designing and Understanding the Human-Nature Connection*. Washington D.C.: Island Press, 63-89.
- Kellert, S., and Wilson, E.O. (1993), The Biological Basis for Human Values in Nature. In: Kellert, S. and Wilson, E.O., *The Biophilia Hypothesis*. Washington D.C.: Island Press.
- Knez, I. (1995), Effects of indoor lighting on mood and cognition. *Journal of Environmental Psychology*, 15, 39–51 (doc 11).
- Lohr, V.I. (2000), Physical discomfort may be reduced in the presence of interior plants. *Hort Technology* , 10, 53-58(doc 1).
- Marchant B. (1982), A look at the industry - dimensions and prospects. *Amer. Nurseryman* 156 (10): 30-49.
- Mayer F.S. & C.M. Frantz (2004), The Connectedness to Nature Scale: A Measure of individuals' feeling in community with nature. *Journal of environmental Psychology*, 24, 504-515 (doc 1).
- Mayer F.S. & C.M. Frantz et al (2006), Why is nature beneficial? The role of connectedness to nature. *Journal of Environmental Psychology* (doc 1).
- Moore, R.C., and Cooper Marcus, C. (2008), Healthy planet, healthy children: Designing nature into the daily spaces of childhood. In: Kellert, S., Heerwagen, J. and Mador, M. (Eds.), *Biophilic design: Theory, science and practice*. Hoboken, NY: John Wiley & Sons.
- Ottoson J. & P. Grahn (2005), A comparison of leisure time spent in a garden with leisure time spent indoors: On measures of restoration in residents of geriatric care. *Landscape Research*, 30 (1), 23-55. (doc 1).
- Shoemaker C.A. (1992), Relationships between Plants, Behaviour, and Attitudes in an Office Environment. *Hort technology* 2 (2), 205-206 (doc 5).
- Srivens S. (1980), *Interior Planting in Large Buildings*, London: The Architectural Press (doc 7).
- Stec W.J. et al (2005), Modelling the double skin facade with plants. *Energy and Buildings*, 37, 419-427 (doc 5).
- Stone, N.J. (1998), Windows and environmental cues on performance and mood. *Environment and Behavior*, 30, 306–321 (doc 11).
- Strickler B. (1994), Water Evaporation of 5 Common Indoor Plants under Various Climate Conditions, *AIVC*, Vol 1, 151-162 (doc 5).
- Ulrich R.S. (1984), View through a window may influence recovery from surgery. *Science* 224: 420-21 (doc 5, 10).
- Wolverton B.C. (1989), Interior landscape plants for indoor air pollution abatement. NASA, John C, Space Center (doc 2, 4, 5).

Further reading

Csikszentmihalyi, M. (1996), *Creativity: Flow and the Psychology of Discovery and Invention*, Harper Perennial, New York, NY.

Lohr, V.I. (2000), "Physical discomfort may be reduced in the presence of interior plants", *HortTechnology*, Vol. 10 No. 1, pp. 53-8.

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Appendix A: list of the examined 17 research reports

- 1 van den Berg, A., Winsum Westra M. (2006), *Ontwerpen met groen voor gezondheid* [Designing with plants creating health]. Alterra rapport 1371, ISSN 1566-7197 Reeks Belevingsonderzoek nr 14, Wageningen, Alterra.
- 2 Fjeld, T., Bonnevie, C. (2002), Het effect van planten en kunstmatig daglicht op het welbevinden en de gezondheid van kantoorpersoneel, schoolkinderen en gezondheidsmedewerkers [The Effect of plants and artificial daylight on the well-being and the health of office workers, school children and health care Personal] International Symposium Floriade Netherlands.
- 3 Dortmont, J.F., Bergs J.A. (1997), *Planten en productiviteit* [Plants and productivity], Leiden: Bloemenbureau Holland.
- 4 Klein Hesselink, J., Hopstaken, L. (1995), *Planten op het werk* [Plants in the working environment] Amsterdam: NIA.
- 5 Klein Hesselink, J., de Groot, E., Loomans, M., Kremer, A. (2006), *Fysiologische en psychische en gezondheidseffecten van planten in de werksituatie op gezondheid en welbevinden van mensen* [Physiological and mental and health consequences of plants in the work situation on health and well-being of people] TNO rapport 21573/ 018.10311. Hoofddorp: TNO Kwaliteit van Leven.
- 6 Larsen, L., Adams, J., Deal, B., Kweon B, Tyler, E, (1998), Plants in the workplace: The effect of plants density on productivity, attitudes and perceptions. *Environment and Behaviour*, 30, 261-281.
- 7 Lohr, V.I., Pearson-Mims, C.H., Goodwin, G.K. (1996), Kamerplanten kunnen de arbeidsproductiviteit verbeteren en de hoeveelheid stress verminderen in een omgeving zonder ramen [Interior plants may improve productivity and reduce stress in a windowless environment]. *Journal of Environment Horticulture*, 14, 97-100.
- 8 Loomans, M., Klein Hesselink, J. (2005), Het effect van planten op het werk. [The influence of plants in the working environment] *Facility Management Magazine* 133, 17-21.
- 9 Schempp, D. (2002), *Green Architecture, Plants in buildings; Key message Plants for People*, International Symposium Floriade, Netherlands.
- 10 Shibata, S., Suzuki, N. (2001), Effects of indoor foliage plants on subjects' recovery from mental fatigue, *North American Journal of Psychology* Vol. 3 nr. 3, p 385.
- 11 Shibata, S., Suzuki, N. (2002), Effects of an indoor plant on creative task performance and mood. *Journal of Environmental Psychology* 22, 265- 272.
- 12 Ulrich, R. S. (2002), The consequences on health of plants in and around hospitals on patients and nursing staff. Center for Health Systems and Design, Texas A&M University College State.
- 13 van der Wal, J.F. van der (1991), *Oriënterend onderzoek naar de luchtzuiverende werking van potplanten in een mechanisch geventileerde proefruimte* [Orientation study concerning the air cleansing functioning of pot plants in a mechanically ventilated test space] TNO rapport, TNO Bouw, B-91-0137, TNO Delft.
- 14 van der Wal, J.F., Hoogeveen, A. (1993), *Onderzoek naar de regeneratie van actieve kool door potplanten* [Study concerning the regeneration of active cabbage by pot plants] TNO rapport, TNO Bouw, B-92-1155, TNO Delft.
- 15 Wolf, K. L. (2002), *Het effect van natuur in en rond winkelgebieden; creatie van een consument gerichte leefomgeving* [The impact of nature in and around shop areas; creation of an environment specifically suited to a consumer] People/Plant Symposium Amsterdam, Netherlands.
- 16 Wood, R.A., Burchet, M.D., Tarran, J., Torpy, F. (2002), Het vermogen van planten/aarde om schadelijke stoffen uit vervuilde lucht binnenskamers te verwijderen [The capacity of plants/ground to remove indoor detrimental substances out of polluted air] *J Environ. Hort. Biotechnol.* 77 (1), 120- 129.
- 17 Wood, R., Orwell, R., Tarran, J. (2004), *Planten om de luchtkwaliteit van een kantoor te verbeteren* [Plants to improve office air quality] Final report of Office 'On-Location' study, Flower Council of Holland, Sydney.